Lost Talent

The Underparticipation of Women, Minorities, and Disabled Persons in Science

Jeannie Oakes

RAND

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PREFACE

This report reviews current research on the relationship between educational practices and policies and the low rates of participation of women, minorities, and disabled persons in science-related careers. The information presented here should contribute to the ongoing discussion of how schools might create conditions that will both entice underrepresented groups into preparing for mathematics and science careers and help them be successful as they do so. The report has two central messages: (1) There is much we do not understand about the low participation rates of these groups; and (2) what we do know suggests that there are alterable features of schools that appear to constrain participation. The report calls for more sophisticated inquiry and suggests some directions for action.

This review should be of interest to researchers and policymakers seeking to understand the challenge the nation faces as it attempts to increase access to careers in mathematics and science-related fields. It should also be useful to those designing interventions, who must target multiple barriers, many of which are not fully understood.

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SUMMARY

As the nation's economic base shifts increasingly toward technology, U.S. students' participation and achievement in science and mathematics become increasingly important. The current explosion of technology suggests a future economy based increasingly on the size and quality of the technological workforce. Yet even as this sector of the workforce is increasing, the proportion of the U.S. population involved in science and engineering has slipped, compared with Japan, West Germany, France, and the United Kingdom.

Demographic projections add to the concern, for the traditional pool from which scientific workers have been drawn in this country is shrinking. As a result of overall declines in the birthrate since 1964, the pool of 18- to 24-year-olds—the cohort preparing for careers and entering the workforce—will shrink by 23 percent by 1995. The composition of the pool will also change. The number of whites will decline markedly, while the number of minorities will increase. Higher birthrates and immigration will cause the number of minorities in the 18- to 24-year-old group to grow by 20 to 27 percent by 1998. In addition, women will continue making headway in the workforce; they will represent 47 percent of the total workforce and half of those pursuing professional careers. The U.S. Department of Labor estimates that women, minorities, and immigrants will constitute 80 percent of the net additions to the labor force between 1987 and 2000.

The composition of this projected workforce causes great concern for the scientific community. Currently, only 15 percent of employed scientists, mathematicians, and engineers are women; blacks (who constitute 10 percent of all employed workers and 7 percent of professional workers) and Hispanics (5 percent of all workers and 3 percent of professionals) each constitute about 2 percent of the scientific workforce. In addition, women, blacks, and Hispanics are underrepresented among those *preparing* for careers in science. Although women have made great strides in the past decade, they earn only 38 percent of the scientific bachelor's degrees, 30 percent of the master's degrees, and 26 percent of the doctorates awarded in the United States, and most of these are in psychology and the social sciences. Blacks and Hispanics have made little progress: Blacks earn 5 percent of the scientific bachelor's degrees and 2 percent of the doctorates; Hispanics earn 3 percent of the bachelor's degrees and 2 percent of the doctorates. Like women, blacks and Hispanics who earn degrees in science tend to major in

psychology and the social sciences; their percentages have not changed substantially in 10 years.

If the United States is to function effectively in a technology-based economy, it cannot afford to underutilize its workforce so drastically. If the nation continues to rely on decreasing numbers of white and Asian males for scientific talent, the quantity—and quality—of the workforce will be substantially lower than it would be if all groups were included. In addition, as technology becomes increasingly central to work and national life, lack of attainment in science and mathematics will affect the ability of women and minorities to compete for employment, wages, and leadership in any professional field. In a society grounded in the long-standing policy of the fair distribution of economic and social opportunities, such a situation is untenable.

This study explores reasons why women, minorities, and physically handicapped people hold fewer professional jobs in science and technology than white and Asian males, and it suggests potential solutions to the problem.

Schooling rests at the heart of the issue. Careers in science and technology result from students passing through a long educational "pipeline." Doing so successfully involves three critical factors: *opportunities* to learn science and mathematics, *achievement* in these subjects, and students' *decisions to pursue* them. Women and minorities lose ground on all three factors, but in different ways and at different points in time. Very little is known about the movement of physically handicapped people through the pipeline.

The pool of scientific/mathematical workers moves into the pipeline during elementary school and reaches its maximum size before 9th grade. During high school, some additional students enter the flow, but considerably more leave. Following high school, the movement is almost entirely outward. In elementary school, students' early achievement in mathematics appears related to their interest in science and math, and to the science-related experiences they have both in and out of school. In many schools, the students with the highest interest and achievement have enhanced opportunities to learn science and mathematics through being placed in special enrichment programs.

As students move into middle schools and junior high schools, those with high interest and/or high scores on basic-skills tests move into advanced classes that prepare them for high school mathematics. In contrast, students who lack interest and/or have low test scores are often assigned to remedial, review, or practical classes, where they are not prepared for advanced senior high school science and mathematics courses. Such students leave the scientific pipeline at this juncture.

In senior high school, students' achievement and curricular choices influence their subsequent opportunities. Typically, high-achieving students who plan to attend college enroll in programs that require a greater number of mathematics and science courses. Lower-achieving students enroll in vocational or general programs that require fewer such courses. Those who enroll in mathematics and science courses beyond the program requirements are those with both high interest and high achievement. On the whole, these are the students who choose mathematics and science majors in college, the next major juncture in the pipeline.

Once a student is in college, persistence in a scientific major becomes crucial to emerging from the pipeline into a scientific career. At this stage, persistence seems to be related to high school achievement (as measured by SAT scores), high school grades, high school class rank, and grades earned in college.

While women and minorities drop out of the pipeline at various stages, women tend to leave primarily during senior high school and college, while blacks and Hispanics leave much earlier. Furthermore, women leave because they *choose* not to pursue scientific careers, while blacks and Hispanics leave principally due to low achievement in mathematics during the precollege years. Gender differences in mathematics achievement are nearly nonexistent in both elementary and junior high school; by senior high school, though, achievement differences become evident. At the same time, elementary school girls show less positive attitudes toward science and science careers than do boys, and the gap widens in junior high; by senior high school, girls exhibit a more negative attitude, pursue fewer mathematics and science opportunities, and score considerably less well than boys on measures of mathematics and science achievement. In contrast to women, blacks and Hispanics consistently demonstrate high interest in mathematics and science, but their lower achievement often places them in remedial programs from elementary school on, thus limiting their opportunities for science-related experiences. By the time blacks and Hispanics reach senior high school, the achievement gap between them and whites has widened, effectively blocking them from mathematics and science opportunities beyond high school.

If the situation is to be remedied, it will be necessary to intervene at those junctures in the pipeline where students drop out, and the interventions must be appropriate to each group. Although many intervention programs exist and evaluation data have been collected and reported on their effects, few programs have been subjected to systematic inquiry. Nor has much empirical work been done on the causes of underparticipation or on ways to address those causes. The available research suggests that altering the way science and mathematics are taught can promote girls' achievement and the likelihood of girls choosing to study these subjects. Likewise, minority achievement can be increased by providing additional, positive science and mathematics experiences both in and out of school, as well as providing altered instruction, career information, and contact with role models.

Much remains to be done, however. First, it is essential to monitor more closely the overall trends in the status of women and minorities in science and mathematics and to translate the data collected into useful "indicators" for policymakers and educators. Presently, for example, the data available are inadequate to permit studies of racial and ethnic subpopulations; typically, Mexican-Americans, Central Americans, Puerto Ricans, and Cubans are lumped together as Hispanics, while the Asian category includes such diverse groups as Chinese, Vietnamese, Japanese, and Filipinos. Second, we must know much more about how schooling relates to minority students' learning opportunities, achievement, and decisions about their future careers, especially at the elementary school level. Finally, it is necessary to explore how individual and social factors interact with girls' attitudes about science and mathematics and how that interaction affects girls' choices not to participate in scientific careers.

CONTENTS

I. OVERVIEW

As the nation's economic base shifts increasingly toward technology, disparities in students' achievement and participation in science and mathematics are generating increasing concern. This concern is heightened by demographic projections which show that the traditional pool of scientific workers is shrinking. Future cohorts of workers will comprise increasing proportions of women and minorities—groups that traditionally have been underrepresented in scientific and technological fields. These changes have triggered a number of policy questions: How can we ensure a sufficient future supply of highly trained mathematicians, scientists, and engineers? How can we provide the general labor force with the knowledge and skills needed for technological work? How can we attain the level of scientific literacy necessary for responsible, democratic decisionmaking about scientific and technological matters? These questions have no clear-cut answers. However, many observers suggest that without substantial increases in the achievement and participation of women, minorities, and disabled people in scientific and technological fields, the nation will not meet its future demands.

Aligned with these human capital issues is the long-standing policy objective of a fair distribution of economic and social opportunities. As technology becomes increasingly central to work and national life, the attainment of women, minorities, and physically disabled people in science and mathematics will increasingly influence their ability to compete for employment, wages, and leadership positions. These groups, more than ever before, stand to be disadvantaged if they fail to acquire science-related knowledge and skills that will prepare them for scientific and technological jobs.

Since schooling is at the center of these concerns, policymakers are paying increasing attention to the quality of mathematics and science education—as both a contributor to the underparticipation problem and a potential solution to it. However, pinpointing the causes of underrepresentation and identifying ways to remedy it have proven difficult. Recent research has provided valuable information about the educational "pipeline" through which all scientific personnel flow, and about the participation and achievement of women and black and Hispanic minorities at critical junctures in that pipeline. Studies have examined ways in which women and minorities differ from white males that are thought to be linked with attainment in scientific fields. This work suggests that three factors are critical: (1) opportunities to learn science and mathematics, (2) achievement in these subjects, and (3) students' decisions to pursue them. Minorities and women lose ground on all three factors. However, different groups lose ground in science and mathematics in different ways and at different points in time.

Despite these insights, the *causes* of low achievement and participation are poorly understood, and little is definitively known about policies and programs that can be expected to improve the current situation. Moreover, interventions aimed at increasing participation by women and minorities have not been systematically studied. Nonetheless, some promising clues have emerged. Girls, minorities, and disabled students are typically encouraged less than white males and have fewer science- and mathematics-related opportunities either in school or out. When encouragement and opportunities are present, however, these groups seem to respond in much the same way as white males—with interest and participation. Consequently, it may be possible to increase participation with school conditions and special interventions that provide these additional supports. Considerable further research is needed to determine what types of programs will be most successful and at what points in students' school careers various strategies are likely to be most productive.

Section II presents an overview of the problem of underrepresentation of minorities, women, and the physically handicapped in the science-related workforce, including data on the current status and recent trends in the participation of these groups and a summary of related policy concerns. Section III describes the schooling process (the "pipeline") by which students become scientists and discusses race and gender differences in participation. The next three sections describe potential influences on the learning opportunities, achievement, and choices of women, minorities, and disabled persons. These influences include individual attributes (cognitive abilities and attitudes), schooling features, and societal factors. Section VII describes intervention strategies that have been designed to reverse underparticipation. The report concludes with suggestions for future policy-relevant research.

This study has several limitations. First, some of the topics addressed have generated a rather substantial literature, while others have received considerably less attention. Rather than attempting to provide a comprehensive review, we have summarized major findings, using selected illustrative studies. The intent is to synthesize what is known from the best available studies, identify uncertainties, and suggest areas that are not well understood. Second, the broad scope of this report (along with the limitations in the research) prevents a detailed accounting of the experiences of specific minority groups, consideration of gender groups separately within racial and ethnic groups, or discussion of different disabling conditions. Rather, the experiences of blacks and Hispanics are presented as representative of the problems faced by underrepresented minorities, and for the most part, there is no discussion of variations within groups of women and disabled persons. Third, because Asians are generally overrepresented in science, their experiences are not considered here. Finally, the recent growth in the number of foreign-born students in college and graduate-level science and mathematics programs is mentioned only briefly.

II. REPRESENTATION OF WOMEN, MINORITIES, AND DISABLED PERSONS IN THE SCIENTIFIC WORKFORCE: CURRENT STATUS AND POLICY CONCERNS

CURRENT STATUS AND TRENDS

Women and non-Asian minorities are significantly underrepresented in the science, mathematics, and technology workforce. Although by 1986 women made up 49 percent of the professional workforce, they constituted only 15 percent of the employed scientists, mathematicians, and engineers.[1] In the same year, blacks (who constitute 10 percent of all employed workers and 7 percent of professional workers) and Hispanics (5 percent of all employed workers and 3 percent of professionals) each represented about 2 percent of the scientific workforce. Approximately 2 percent of the scientists and engineers were physically disabled, according to self-reports (National Science Foundation, 1988). While comparable figures are not available for disabled persons in the general workforce, 3 percent of all employed persons in 1985 reported that they had work disabilities (U.S. Department of Commerce, 1987).

During the past two decades, women and blacks have made some progress in reducing participation gaps. Women's current 15 percent share of the scientific workforce grew from 9 percent in 1976.[2] Blacks increased their participation in science careers by 140 percent between 1976 and 1984, compared with a 70 percent growth rate for whites (however, the black growth rate stems from a much smaller base) (National Science Foundation, 1986).[3]

Despite these gains, women and minorities trained in scientific fields are more often underutilized in the workforce, and they are paid less than their male and white counterparts. In 1986, 25 percent of the scientifically trained women were employed in work unrelated to science, compared with 14 percent of their male counterparts (National

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[1]Roughly 5 percent of these women were black; almost 3 percent were Hispanic.

[2]This represents a 250 percent increase in scientific employment for women, compared with an 84 percent increase for men in the same time period. During these same years, women's share of the total workforce increased at a somewhat slower rate, growing from 33 percent to 44 percent (U.S. Department of Commerce, 1987).

[3]Increases for Hispanics did not exceed those for scientists generally during this period.

Science Foundation, 1988).[4] While some gender disparities result from the recency of many women's entry into the workforce, differences are found even among the most recent science graduates (National Science Foundation, 1988).[5] Racial disparities exist as well. It is difficult to separate employment choices from the ability to secure desired employment, but black and Hispanic male scientists have somewhat lower rates of science-related employment than their white male counterparts.[6] Among academic scientists, men are far more likely than women to hold tenure track positions, to be promoted to tenure, and to achieve full professorships. This finding holds even when analysts control for such factors as field of specialization, quality of graduate school attended, and years of experience beyond doctoral degrees (National Science Board, 1987).

As noted above, female scientists and engineers, on the average, earn less than their male counterparts.[7] While some of this difference can be explained by the fact that women scientists are generally younger than men and have fewer years of experience, women with experience equivalent to that of men also tend to earn less. Moreover, black and Hispanic scientists and engineers earn less, on average, than do whites and Asians (National Science Foundation, 1988).[8]

Women, blacks, and Hispanics are also underrepresented among students preparing for careers in science. While women have increased their rate of scientific preparation substantially since 1970,[9] much of

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[4]In 1984, 29 percent of black and 27 percent of Hispanic women scientists held non-science-related jobs (Scientific Manpower Commission, 1986).

[5]Fifty-three percent of the women and 70 percent of the men awarded science baccalaureates in 1984 and 1985 (and not attending graduate school) were employed in science-related jobs; 78 percent of the women and 87 percent of the men receiving master's degrees had found related work.

[6]In 1986, black male scientists had a scientific employment rate of 76.5 percent; Hispanic males, 80 percent; and white males, 84.9 percent.

[7]Across all fields, women's salaries in 1986 averaged about 75 percent of men's. Moreover, in 1986, women doctoral scientists and engineers earned an average of 80 percent of the salaries of their male counterparts.

[8]In 1986, blacks earned 81 percent and Hispanics 88 percent of the salaries of white scientists and engineers.

[9]In 1985, women earned almost 38 percent of the scientific bachelor's degrees awarded in the United States, an increase of 30 percent since 1975. Similar changes occurred at the graduate level, where women earned 30 percent of the master's degrees, a 20 percent increase since 1975; and in 1986, women earned 26 percent of the doctorates, an increase of 17 percent. While women's science-related degrees remain concentrated in psychology and the social sciences, and the proportion is exceptionally low in engineering (about 14 percent at the bachelor's and 11 percent at the master's level), the share of bachelor's degrees in engineering awarded to women increased twelvefold between 1975 and 1985. However, the percentage of doctorates awarded to women increased in only two scientific fields—engineering and the social sciences (National Science Foundation, 1988).

this increase is attributable to the greater numbers of women obtaining college degrees generally (Berryman, 1983). On the other hand, blacks and Hispanics have experienced little change in degree attainment at any level.[10] Important differences appear *within* minority groups as well, with black males particularly disadvantaged in degree attainment.[11] No data are available that track the preparation rates of physically disabled students.

Although both women and non-Asian minorities remain significantly underrepresented in scientific fields of study and work, women appear to have made considerable progress in gaining access to scientific preparation over the past two decades. However, two factors dampen optimism that their underrepresentation will simply take care of itself over time. First, past increases in women's participation must be attributed to their increased participation in higher education generally, as well as to a proportionate increase in their choice of scientific fields. With women now attaining 50 percent of the degrees overall, future increases will depend more heavily on women's switching from other fields of interest (Berryman, 1983). Second, women continue to be at a considerable disadvantage in obtaining comparable scientific employment and salaries. As will be discussed later, these disadvantages may hamper efforts to encourage women to enter scientific fields.

In contrast to the more positive trends for women, blacks and Hispanics have made little progress. Their lower and constant rates of participation are limited by their lower rates of degree attainment (and, as will be discussed at length in later sections, by their precollege experiences) and by the smaller percentage of scientific majors among those who do attain college degrees. Moreover, minority workforce participation may be constrained by factors in the job market, such as higher rates of unemployment, underemployment, and lower salaries among minority scientists.

[10] In 1985, blacks earned 5 percent of the scientific bachelor's degrees and 2 percent of the doctorates. Hispanics earned 3.1 percent of the bachelor's degrees, 2.7 percent of the master's, and 2 percent of the doctorates. These percentages show little change since 1979. Both blacks' and Hispanics' science-related degrees are concentrated in psychology and the social sciences, and both groups remain highly underrepresented in other scientific fields. In 1986, blacks received far smaller percentages of natural science and mathematics doctorates—only slightly more than 1 percent of those in physical sciences, mathematics, computer science, and life sciences. They earned 2 percent in engineering. Hispanics showed similar underrepresentation—1 percent in physical sciences, 2 percent in mathematics, 3 percent in computer science, 1.4 percent in engineering, and 2.5 percent in biological sciences (National Science Foundation, 1988).

[11] Hall and Post-Kammer's (1987) review of black/white differences in science attainment points out that there are few racial differences among women who receive science or mathematics degrees; however, the rates of black males receiving degrees in science or mathematics are much lower than those of white males.

These data suggest that while women will probably continue to be underrepresented, the gender gap in science will continue to decrease over the next several decades, albeit at a slower pace than in the recent past. However, little in current data or past trends suggests that black and Hispanic participation will increase significantly.

SCIENCE, TECHNOLOGY, AND CHANGING DEMOGRAPHICS

Policymakers' interest in the participation of women, minorities, and people with disabilities in science and mathematics has been heightened by projected changes in social and economic conditions. The current explosion of technology has brought predictions of an economy hinging increasingly on the size and quality of the technological workforce (see, e.g, National Commission on Excellence in Education, 1983; Task Force on Education and Economic Growth, 1983). Between 1976 and 1985, jobs for scientists and engineers increased at three times the rate of U.S. employment generally (National Science Board, 1987). Moreover, some observers suggest that these figures only scratch the surface of the *potential* for expansion. Even as this sector of the workforce has increased, the proportion of U.S. workers in science and engineering has slipped markedly compared with our technological trading partners—Japan, West Germany, France, and the United Kingdom (Bloch, 1986). If these trends continue, growth in technological areas such as computer science, nuclear energy, and genetic engineering portend even greater increases in the demand for highly trained personnel. Many analysts also expect that lower-skill-level jobs will also require higher levels of technological knowledge in the future (e.g., Johnson, 1987).

These predictions are not unequivocally supported, however; other analysts expect technological growth to influence the labor market in another direction—by creating a large proportion of jobs that demand very low skill levels, e.g., jobs in the service sector (fast food restaurants) or in technological support areas such as data entry (Levin and Rumberger, in press). However, it seems most likely that we will experience a mix of both upgrading and downgrading of technical skill requirements for jobs and an evolutionary, rather than a revolutionary change (Spenner, 1985).

In contrast, there is little controversy about who the next generation of workers will be. We can count on a substantial shrinking over the next two decades of the traditional pool of young people from which scientists, mathematicians, and engineers have been drawn. Greater proportions of the young workers will be minorities; many will have first languages other than English; and more than ever before will be women.

Declines in the birthrate since 1964 have resulted in overall decreases in the number of 18- to 24-year-olds—the sector of the population that contains most of the college students and new entrants to the workforce. This group is expected to decrease by 23 percent by 1995, causing the slowest overall growth in the workforce since the 1930s (Johnson, 1987). The composition of this group will also change. The white birthrate has declined more dramatically than that of other groups (U.S. Department of Commerce, 1984), and greater proportions of immigrants have been coming from less-developed nations in Latin America and Asia (U.S. Department of Commerce, 1987). Consequently, the U.S. Department of Commerce (1984) expects the number of minorities in the 18- to 24-year-old group to increase from 20 percent to 27 percent by 1998, and the U.S. Department of Labor predicts that by 1990, about 20 percent of the new entrants to the labor force will be minorities (Johnson, 1987).

Women's labor market participation has also increased dramatically, and this trend is expected to continue (Task Force on Women, Minorities and the Handicapped in Science and Technology, 1988). It is anticipated that by the year 2000, 47 percent of the total workforce will be made up of women—up from only 30 percent in 1950 (Johnson, 1987). Perhaps even more striking is the fact that women currently comprise 49 percent of the workforce in professional careers (Scientific Manpower Commission, 1986). The Department of Labor estimates that women, minorities, and immigrants will constitute 80 percent of the net additions to the labor force between 1987 and 2000 (Johnson, 1987).

We cannot predict the impact these trends will have on the future supply of technological workers. Some observers point to a recent decline in the number of American students choosing to pursue graduate study in mathematics and engineering (Conference Board of Mathematical Sciences, 1987; Ramo, 1987) and to a decrease in the number of women college students studying science (Vetter, 1987) as warning signs of a future shortage. In contrast, however, an analysis conducted by the U.S. Congress Office of Technology Assessment (OTA) in 1985 for the Science Policy Task Force of the House Committee on Science and Technology (OTA, 1986) found that anticipated changes in the size and composition of the student population and workforce do not necessarily pose a threat to the nation's future supply of qualified scientists, mathematicians, and engineers. Scientists (including social scientists) and engineers currently represent only about 3 percent of the workforce, so changes in workforce needs or in the student population are not likely to create demands that outstrip the available supply. The OTA's optimistic conclusion was based on several findings, many of which are drawn from meticulous studies of the supply of and demand for scientists.

First, declines in the size of the 18- to 24-year-old cohort may not result in fewer employable scientists and engineers. Continuing high college enrollment rates of 25- to 44-year-olds and foreign nationals—groups whose college participation has increased dramatically over the past several decades—may compensate for an absolute decline in the number of younger students. Also, labor-market responses to projected shortages such as increased pay and better job opportunities could encourage higher proportions of college students to choose scientific and engineering fields.

In response to increases in labor-market demand, the number of engineering majors doubled between 1976 and 1984, and the number of students majoring in computer and information science increased threefold between 1977 and 1982 (Berryman, 1985). Since only about 30 percent of baccalaureate degrees are now awarded in scientific fields and less than 7 percent of the members of any age cohort receive these degrees, similar shifts could easily offset overall numerical declines.

Additionally, the OTA study argued that about 37 percent of the 1980–81 recipients of scientific bachelor's degrees were neither part of the scientific and engineering workforce nor attending graduate school in 1982, so additional workers could be drawn from this underutilized group (National Science Foundation, 1984a). More recent data show a similar reserve pool.[12] The OTA noted that past increases and declines in the production of Ph.D.s appear to be unrelated to demographic changes; they are instead influenced by such factors as the availability of financial support (Snyder, 1985) and academic and research positions (Cartter, 1979).

The OTA also concluded that, while demand for various types of specialization within science and engineering (e.g., electrical and aeronautical engineers) may increase, other fields (e.g., biology, chemistry, mathematics) will probably experience declines (National Science Foundation, 1984b). Increases in the demand for industrial scientists are likely to be offset by anticipated declines in the academic marketplace (McPherson, 1985; National Research Council, 1985) which may prevent an overall increase in the demand for scientists and engineers. This possibility also bodes well for future supply.

[12]As noted earlier, 22 percent of the men and 47 percent of the women who received scientific baccalaureates in 1984 and 1985 were neither employed in science and engineering jobs nor enrolled in graduate school.

Finally, citing gross inaccuracies in past projections and the lack of reliable methods for forecasting supply and demand, the OTA suggested that "predictions of shortages based on such forecasts should be viewed with considerable skepticism." Little in our past experience can illuminate the implications of current technological changes; much will happen that forecasters cannot anticipate, and changes in any one of many factors can dramatically affect the accuracy of projections (OTA, 1985).

Even if demographic changes do not necessarily portend an imminent shortage of scientists, however, the OTA and other analysts suggest that concern is warranted on other grounds. First, because women and non-Asian minorities are so underrepresented in mathematics and science, considerable talent is undoubtedly being lost. Such losses have implications for both the *size* and the *quality* of the available pool of scientific talent. If the nation continues to rely on white and Asian males (who currently comprise less than 50 percent of the total population and will comprise less than 40 percent by 2000) for scientific talent, the quality of the scientific workforce could be substantially below what it would be if all groups were included. Declines in the size of the college-age cohort underscore the importance of fully developing human resources in all sectors of the population, and underrepresented groups provide an important source of new talent (OTA, 1986, 1988). Erich Bloch, director of the National Science Foundation, recently noted:

> We must find ways to use the latent talent of women and minorities that are now underrepresented in science. There is an equity issue here, and that has been the focus of attention. But progress on this issue is also important in economic terms. No society that expects to remain competitive can afford to allow talented people not to be fully utilized (Bloch, 1986, p. 599).

There is also concern that analyses of the match between future supply and demand based on only past or current experience may overlook other important considerations. The absence of a shortage in a particular field does not necessarily mean that the *quality* of the participants in that field is sufficient. Some of the apparent "balance" comes from less-qualified people filling slots that would otherwise be left empty. Moreover, such analyses may underestimate the nation's potential to productively accommodate an increasing number of well-trained scientists and engineers. Recent studies of the relationship between the quality of education and economic growth suggest that increasing the quality of education—particularly for disadvantaged students—may itself result in increased productivity and economic growth (see Solomon, 1985, for a review). In a technologically based society, such growth may lead to an increased demand for scientifically trained personnel. That is, higher-quality education may affect economic growth by producing increases in research, technological applications, *and* the number of individuals prepared to adapt and use technologies. New scientific knowledge may actually generate new technologies, promote the application of those technologies in the marketplace, and, as a result, create additional demand for scientifically trained personnel. This process could be facilitated, in part, by providing higher-quality science and mathematics education to minority groups and women.

Finally, in addition to concerns about the quantity and quality of the scientific workforce, there is also considerable worry that anticipated population changes will lead to a shrinking proportion of Americans who are well-educated in science and mathematics. Many analysts forecast that the lack of a solid mathematics education for all has very broad implications. Rapid changes in technology are altering the nature of most work, and more jobs are requiring skills that are acquired in mathematics and science education. In addition, since national decisions will increasingly concern matters related to technology—e.g., in areas such as energy, health care, and the environment—responsible, democratic decisionmaking will require greater understanding of science and technology among all citizens. As the bases of the economy, social welfare, and national defense shift increasingly toward science-related activities, current patterns must be altered, or else a smaller proportion of the population will have opportunities to participate in those pursuits most central to either personal advancement or national well-being.

In short, the anticipated need to maximize the human-resource potential of all sectors of the population is compounded by a more general worry about providing opportunities for all groups to become scientifically literate and to pursue careers in scientific fields. Together, these growing concerns suggest that the participation of women, minorities, and disabled people in science and mathematics is an appropriate policy issue, whether or not actual shortages of scientists are in the offing.

III. WOMEN, MINORITIES, DISABLED PERSONS, AND THE SCIENTIFIC PIPELINE

To understand the low participation rates of women and non-Asian minorities in scientific careers, we must first understand the educational experiences of all people in training for scientific careers. We also must understand how women and minorities fare in this scientific "pipeline." Recent analyses have identified a critical sequence of precollege and college events that provide students with the prerequisites for adult participation in science. Other work describes how women and minorities differ from males and whites in their participation at critical points along the pipeline. Unfortunately, virtually no data are available to track the participation of physically disabled people.

THE PIPELINE

Berryman's 1983 landmark study, *Who Will Do Science?*, addresses several important questions about the educational pipeline and the formation of the "talent pool" from which scientific professionals are drawn:

- When does a pool of students with scientific interests first emerge in the educational pipeline?
- When does the pool seem to reach its maximum size?
- What are the rates of migration into and out of the pool as it moves through the pipeline?
- What relationships exist between scientific field interests and mathematical talents at different points in the pipeline?

Berryman concluded that the scientific/mathematical pool first appears in elementary school, and it emerges strongly and reaches its maximum size before the 9th grade. During high school, there is some additional movement of students into the pool, but considerably more students leave. Following high school, the flow is almost entirely outward. Consequently, students should be encouraged to enter the scientific pipeline prior to high school, but keeping them in the pipeline requires attention at all levels. Berryman also concluded that both talent and interests are relevant to persistence in the pipeline, but in different ways for different groups (Berryman, 1983).

A number of other studies support Berryman's conclusion that both talent (i.e., achievement) and interests (i.e., choices) are important for students to remain in the pool of potential scientists. However, a third factor, opportunity—i.e., the access students have to science and mathematics experiences both in and out of school—is also central to pipeline persistence. Opportunity, achievement, and choice appear to be highly interrelated, although possible causal links among them are not well understood.

The following discussion of the educational pipeline is applicable to the general student population as well as to prospective scientists. The schooling experiences that lead to adult participation in science are also those that promote high levels of scientific literacy among students who do not pursue scientific careers.

Elementary School. Students' early achievement in mathematics appears to relate both to their interest in science and mathematics and to their science-related experiences both in and out of school (Armstrong, 1980). In many schools, students with the highest achievement have enhanced opportunities to learn science and mathematics, since they are the ones likely to be selected for special enrichment programs.

Transition to Secondary School. Achievement and interest in mathematics and science in elementary school influence the opportunities of many students to learn these subjects in middle schools and junior high schools. Those who exhibit high interest and/or achieve high scores on tests of basic skills are often placed in classes that prepare them for or even begin high school mathematics course sequences. Many junior high schools offer pre-algebra and algebra, and a few even offer geometry for high-achieving students. In contrast, students exhibiting a lack of interest and/or low test scores are often assigned to remedial, review, or practically oriented classes, where they may have little exposure to topics and higher-order thinking skills that would prepare them for advanced courses (e.g., algebra) in senior high school (McKnight, Crosswhite, Dossey, Kifer, Swafford, Travers, and Cooney, 1987; Oakes, 1985). These students are therefore not likely to become part of the scientific talent pool.

Senior High School Curriculum Enrollment. Students' achievement and curricular choices upon entering high school influence their subsequent opportunities to enroll in various mathematics and science courses (Alexander and Cook, 1982). Typically, high-achieving students who plan to attend college enroll in academic curricula that require them to take more mathematics and science courses than other students and to take courses that cover advanced concepts and processes. Although requirements vary, most four-year colleges expect students to complete more coursework in mathematics and science than the minimum necessary for high school graduation. Coursetaking is also predictive of students' end-of-high-school scores on achievement measures and their readiness for college-level work (e.g., preparation for calculus) (Walberg, Fraser, and Welch, 1986; Welch, Anderson, and Harris, 1982).

Lower-achieving students usually enroll in vocational or general curricula that require fewer mathematics and science courses (Guthrie and Leventhal, 1985). Unlike college-preparatory classes, nonacademic math and science courses are often nonsequential, and most of them emphasize low-level topics and skills (Oakes, 1985).

Election of Additional Courses. Upon completion of college-preparatory requirements, students who elect to take additional mathematics and science courses will have additional preparation for majoring in scientific fields in college. Enrollment in nonrequired science and mathematics courses is related to students' interest in these subjects, their perceptions of their prospects for success, and their prior achievement (Lantz and Smith, 1981). Teacher, counselor, and parent encouragement (usually based on these same factors) may also influence students' decisions to enroll in additional science and mathematics courses (Cicourel and Kitsuse, 1963; Rosenbaum, 1976; College Entrance Examination Board, 1986; Gross, 1988).

College Attendance and Choice of a Scientific Major. Attending college and choosing a scientific major are key to pipeline persistence. Both are strongly related to end-of-high-school achievement and completion of advanced mathematics and science courses (Ware and Lee, 1985). Mathematics preparation may be particularly critical, since at many colleges, readiness for college-level calculus is a prerequisite to admission for quantitative majors (Sells, 1982). However, students' confidence in their abilities and their attitudes toward mathematics and science are also related to their major field choice (Betz and Hackett, 1983; Ware and Lee, 1985).

Persistence in a Scientific Major. Students who persist in a scientific major throughout the undergraduate years and attain baccalaureate degrees in quantitative fields become eligible for graduate school or immediate employment in science-related work. Persistence as science majors seems to be related to students' high school achievement (as measured by Scholastic Aptitude Test (SAT) scores), high school grades, and high school class rank (Matyas, 1986), as well as to grades earned in college (Schonberger and Holden, 1987).

Completion of Graduate Work. Pursuit of the highest level of scientific work requires high achievement in quantitative fields during undergraduate study, admission to graduate school, choice of a scientific graduate field of study, and the attainment of one or more graduate degrees.

Many of the pipeline junctures are obvious, yet they hold the key to understanding adult participation in mathematics and science. As suggested earlier, students' *opportunities to learn mathematics and science*, their *achievement in these subjects*, and the development of attitudes and interests that lead them to *choose to pursue mathematics and science study* are central to successful progress through this pipeline and to later participation.

WHERE ARE WOMEN AND MINORITIES LOST?

Using national data, Berryman found that losses of women from the pipeline occur primarily at the end of the precollege years and during college. The lower adult participation rates of women were traced to two factors: (1) they obtain advanced degrees at lower rates generally, and (2) they select quantitative college majors at lower rates than men do. In contrast, most blacks and Hispanics are lost to science much earlier in the schooling process, and other minority losses occur throughout the years of schooling (Berryman, 1983). The underparticipation of minorities thus can be largely attributed to their lower levels of achievement in mathematics during the precollege years. However, even those blacks and Hispanics who remain in the precollege pipeline are less likely than whites to choose quantitative fields of study (Berryman, 1983).

Early Schooling Experiences

Elementary School. The first signs of black and Hispanic students' divergence from the scientific pipeline appear early in elementary school. White and Asian children more often exhibit high early achievement in mathematics and science than do non-Asian minorities.[1] As a result, blacks and Hispanics are more likely than whites to be placed in low-ability and remedial classes or in special education programs (Persell, 1977; Rosenbaum, 1980), and they are less likely to

[1]For example, by age 9, minority students score substantially lower than whites on National Assessment of Educational Progress (NAEP) ratings in both mathematics and science (Carpenter, Matthews, Lindquist, and Silver, 1983; Hueftle, Rakow, and Welch, 1983; Dossey, Mullis, Lindquist, and Chambers, 1988; Mullis and Jenkins, 1988). In 1986, 9-year-old whites attained an average overall mathematics score on the NAEP of 59; Hispanics averaged 47, and blacks, 46. Nevertheless, minorities have made steady gains over earlier assessments. Black 9-year-olds had gained more than 5 points in mathematics since the 1976 NAEP; Hispanic 9-year-olds gained slightly more than 1 point; and their white counterparts gained 1.5 points (Dossey et al., 1988).

be placed in enriched or accelerated programs (NCES, 1985a).[2] Despite these disparities, black elementary school students are often as enthusiastic as whites about science and mathematics, and they often express the most positive attitudes of any group (Carpenter, Matthews, Lindquist, and Silver, 1983; Mullis and Jenkins, 1988).

Girls' elementary school achievement and opportunities follow a more positive course. Overall gender differences do not appear at the elementary level in either mathematics or science (Lockheed, Thorpe, Brooks-Gunn, Casserly, and McAloon, 1985; Dossey et al., 1988; Mullis and Jenkins, 1988). However, there are some early warning signals of potential gender-related differences: Teachers assign high-ability boys to top mathematics groups more frequently than they assign high-ability girls (Hallinan and Sorensen, 1987). In addition, girls of elementary school age show less positive attitudes toward science and science careers than do boys (Mullis and Jenkins, 1988), and they report fewer science experiences (Mullis and Jenkins, 1988).

Middle School and Junior High School. In junior high school, minority children continue to move out of the pipeline. As in elementary school, blacks and Hispanics are more often placed in remedial mathematics programs (Persell, 1977), where they are likely to be exposed to fewer topics and skills (McKnight et al., 1987). Some groups experience differences in science opportunities as well, since many junior high schools differentiate the science curricula, and some base grouping decisions on mathematics achievement (Oakes, 1985). While the differences have narrowed considerably over the past decade (Jones, 1984), the achievement gap between blacks and whites in junior high school remains, even in low-level topics and skills (NAEP, 1983; Hueftle, Rakow, and Welch, 1983; Dossey et al., 1988; Mullis and Jenkins, 1988). Nevertheless, black students' attitudes toward science and mathematics are as positive as those of their white peers (Mullis and Jenkins, 1988; Dossey et al., 1988).

Gender differences in mathematics achievement are nearly nonexistent at the junior high school level (Dossey et al., 1988). In the past, girls of this age were more negative about mathematics (Fennema and Sherman, 1977), but on some measures these differences have nearly disappeared over time (Dossey et al., 1988). However, girls remain more negative than boys about science, and they report having fewer science experiences than boys (Mullis and Jenkins, 1988).[3]

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[2] On the NAEP, minority students report fewer science-related experiences than do whites (Mullis and Jenkins, 1988).

[3] One recent study of sex-by-race interactions found sex differences among black students, with boys outperforming girls on a combined mathematics and science achievement measure (Langer, Kalk, and Searls, 1984).

Senior High School

Minorities and girls continue to be lost from the scientific pipeline in senior high school. Minorities typically have fewer opportunities to learn science and mathematics, and achievement gaps between black and Hispanic minorities and whites at this level are larger than those for younger students, although these differences, too, have narrowed appreciably. Girls exhibit more negative attitudes, pursue fewer opportunities, and by the end of high school score considerably less well than boys on measures of mathematics and science achievement.

Minority Curriculum Enrollment and Coursetaking. Disproportionately high percentages of minorities enroll in vocational and nonacademic curriculum tracks (Ekstrom, Goertz, and Rock, 1988; West and Gross, 1986). Non-Asian minorities typically take fewer high school science and mathematics courses than do whites, partly because nonacademic-track students usually lack the prerequisites to enroll in academic courses, and also because they are nearly always required to take fewer science and mathematics courses than are college-bound students (California State Department of Education, 1984; Gamoran, 1986; Guthrie and Leventhal, 1985; Vanfossen, Jones, and Spade, 1985). However, even students in college-preparatory programs at low-socioeconomic-status (SES) schools—the schools most minorities attend—typically take fewer academic classes (Rock, Braun, and Rosenbaum, 1985).

As Table 1 shows, substantially lower percentages of blacks and Hispanics concentrate heavily in mathematics and science or complete four-year college-entrance requirements in these subjects. Differences are also substantial in computer-science coursetaking.[4] However, these patterns may be changing somewhat. Data from the American College Testing (ACT) program show a substantial increase between 1978 and 1986 in the number of college-bound students taking three or more years of mathematics and natural science, with dramatic increases in such coursetaking by blacks and Hispanics. However, minority high school students are still underrepresented in advanced courses (Bartell and Noble, 1986).

Minority Achievement and Attitudes. While blacks and Hispanics express very positive attitudes about mathematics (Dossey et al., 1988), they consistently perform less well than white males on measures of end-of-high-school achievement in mathematics and

[4]These data, from High School and Beyond (HSB), parallel findings about differential course participation from the NAEP. In 1980, only 15 percent of black and Hispanic students had completed trigonometry, as compared with 27 percent of whites and 50 percent of Asians (Armstrong, 1981).

Table 1

ACADEMIC COURSETAKING PATTERNS OF STUDENTS, BY SES AND RACE

(Percentages of students exhibiting pattern)

	SES			Racial Group		
Course	High	Middle	Low	White	Black	Hispanic
Academic math	69.1	45.7	25.1	51.5	28.1	28.9
Academic science	58.3	36.9	19.6	40.7	26.1	23.8
Computer science	17.4	12.4	8.4	13.8	10.5	8.0

SOURCE: National Center for Education Statistics (NCES), 1985b.

science.[5] Achievement gaps also persist among college-bound seniors.[6] Minorities' low achievement at the end of high school is undoubtedly even more profound than test scores imply, considering the disproportionate numbers of blacks and Hispanics who drop out of school and are not represented in high school achievement statistics.[7] Differences in dropout rates exacerbate differences in measured achievement, since the students who leave school before graduation are typically among the lowest achievers (Catterall, 1989a). However, blacks who remain in the precollege pipeline and take the SAT report nearly as great an interest in science majors as do whites (Grandy, 1987).

Women's Coursetaking Patterns. Gender differences at the senior high school level follow different patterns. Relatively equal numbers of high school boys and girls enroll in academic and nonacademic curricula; consequently, similar science and mathematics courses are available to them. However, girls *choose to take these courses at lower rates than boys.* As Table 2 shows, girls are more likely than boys to exit from the pipeline after completing basic college

[5]Despite steady minority gains since earlier assessments, 17-year-old whites outperformed these groups on the most recent NAEP assessments in both science and mathematics, with the greatest disparities in mathematics on measures of higher-level skills and problem solving (Dossey et al., 1988; Mullis and Jenkins, 1988).

[6]The most recent SAT scores reveal a 112-point gap between blacks and whites on the mathematics section of the examination. However, these scores represent a 20-point gain for blacks since 1977 (College Entrance Examination Board, 1987).

[7]HSB data reveal higher sophomore-to-senior dropout rates for blacks and Hispanics than for whites—16.8, 18.7, and 12.2 percent, respectively (NCES, 1985a). Even these statistics underestimate the differences, since many minority youth leave school before grade 10. Census data from 1985, for example, show a 20 percent high school noncompletion rate for black 20- to 24-year-olds, 41 percent for Hispanics, and 16 percent for whites (NCES, 1987).

entrance requirements; and boys are more likely than girls to concentrate (i.e., take additional, unrequired advanced courses) in mathematics, science, and computer science. Gender differences also occur in computer-science coursetaking.

While gender differences follow a consistent pattern across subjects, they are substantially greater in science than in other areas. The greatest discrepancies exist in the physical sciences, especially physics. Mathematics discrepancies reflect differences in enrollment in the most advanced courses, i.e., trigonometry and pre-calculus (Fennema, 1984), and the pre-calculus preparation of high school boys is one and one-half times that of girls (Armstrong, 1981).

These patterns, too, may be changing. A recent study of high school seniors in Rhode Island found no overall gender differences in course enrollment (Rallis and Ahern, 1986),[8] and recent ACT data show

Table 2

ACADEMIC COURSETAKING PATTERNS OF STUDENTS, BY SEX

(Percentages of students exhibiting pattern)

Coursetaking Pattern	Male	Female
Math concentrator	9.3 (53.1)	9.0 (46.9)
Math, four-year-college-bound	34.7 (46.8)	38.5 (52.3)
Science concentrator	11.6 (61.4)	7.1 (38.6)
Science, four-year-college-bound	26.6 (38.6)	28.8 (61.4)
Computer-science participant	13.6 (53.8)	11.4 (46.3)

SOURCE: NCES, 1985b.

NOTE: The figures in parentheses represent the percentage of students within each pattern who possess the designated characteristic (male or female). For example 53.1 percent of all the math concentrators are male.

[8]Males tended to outnumber females in pre-algebra and algebra I, but the reverse was true in more advanced mathematics courses. Moreover, the Rhode Island boys had not taken more advanced science courses by the senior year, although more girls had enrolled in chemistry and more boys had taken computer science.

increasing percentages of girls completing three or more years of mathematics and natural science (Bartell and Noble, 1986).[9]

Women's Achievement and Attitudes. By the end of senior high school, gender differences appear in both achievement and attitudes. Achievement differences in mathematics and science appear both among the general student population on NAEP results and among the college-bound on the SAT.[10] High school girls express more negative attitudes toward mathematics (Dossey et al., 1987) and science (Mullis and Jenkins, 1988) than do boys. Moreover, while gender differences in mathematics have decreased during the past decade (Dossey et al., 1988), girls continue to express more negative attitudes than boys toward science (Mullis and Jenkins, 1988).

PRECOLLEGE EXPERIENCES OF DISABLED STUDENTS

Few data exist that track the precollege achievements, opportunities, and choices of physically disabled students in science and mathematics. However, some evidence suggests that as a group they may have fewer opportunities than their nondisabled peers. For example, HSB data show that students with self-reported physical disabilities are more likely than other students to be placed in general, rather than academic, tracks (NCES, 1985a). To the extent that these students are not in academic programs in high school, we can predict their usual coursetaking patterns: fewer science and mathematics courses overall, and lower rates of participation in advanced courses.

The HSB data provide some indication of the overall academic achievement of physically disabled students. Of the sophomores who identified themselves as participating in a program for the physically disabled in 1980, 33 percent scored in the lowest quartile of the study's achievement test (as compared with 20 percent of the nondisabled); 23 percent reported they received grades of Cs and Ds (compared with 18 percent of nondisabled students); 17 percent reported that they had repeated a grade in school (compared with 12 percent) (NCES, 1985c). These data suggest that achievement of physically disabled students in science and mathematics is lower than that of their nondisabled peers.

While statistical data are not available, considerable anecdotal evidence suggests that disabled students are sometimes barred from par-

[9]Recent analyses of data from Montgomery County, Maryland, high schools, however, provide evidence of continuing gender differences in advanced mathematics courses—e.g., accelerated algebra II, computer mathematics, elementary functions and analytic geometry, and calculus (West and Gross, 1986).

[10]In 1985, the mean SAT quantitative score for men was 499; for women, it was 452 (Statistical Abstracts of the United States, 1987).

ticipating in science activities, and many teachers have lower expectations for their academic success (Stern, 1987).

COLLEGE EXPERIENCES

College Attendance. The rates of college entrance by black and Hispanic high school graduates are lower than those of whites.[11] Further, those minorities who do enroll are more likely than whites to attend two-year rather than four-year colleges,[12] and those minorities who do attend four-year schools are less likely to be at universities than colleges (Center for Statistics, 1986b). Additionally, gaps in the percentages of blacks, Hispanics, and whites completing four-year college programs are widening.[13]

Women have slightly higher college entrance rates than men.[14] However, women drop out of college earlier than men, although their eventual completion of a bachelor's degree appears to be equal.[15]

A 1979 study of the college participation of disabled students found considerable underrepresentation. While 8 percent of the population between 16 and 25 years of age was identified as physically disabled, this group represented less than 3 percent of college freshmen (Cooperative Institutional Research Program (CHIRP), 1979).[16] Anecdotal data suggest that restricted access to precollege opportunities

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[11]Among 1980 seniors in the HSB sample 47 percent of the white students, 40 percent of the blacks, and 34 percent of the Hispanics were enrolled full-time in postsecondary institutions in the fall of 1980 (Center for Statistics, 1986b).

[12]Among all students enrolled full-time in the fall of 1986, 43 percent of the blacks, 36 percent of the whites, 55 percent of the Hispanics were enrolled in two-year institutions (NCES, 1988).

[13]For example, by 1983, 34 percent of the black 1980 high school seniors who began full-time college study in the same year and 40 percent of the Hispanics were no longer enrolled, compared with a 29 percent attrition rate for whites (Center for Statistics, 1986b). By 1986, 20 percent of the white 1980 seniors had attained bachelor's degrees, while only 10 percent of the blacks and 8 percent of the Hispanics had done so (Center for Educational Statistics, 1988).

[14]Of the 1980 senior high school class, 45 percent overall were full-time college students in the fall of 1980. Further, 48 percent of the females were full-time college students, compared with 42 percent of the males (Center for Statistics, 1986b).

[15]By 1983, 36 percent fewer of the female 1980 seniors were enrolled in college, in comparison with only 20 percent fewer of the men. By the third year, then, larger percentages of men in this class were in college than women (Center for Statistics, 1986b). Nevertheless, by 1986, 18 percent of the men and 19 percent of the women had completed bachelor's degrees (NCES, 1988).

[16]These data present some difficulties, since it is also important to understand what portion of the total population of physically handicapped persons is actually physically able to attend college before drawing conclusions about how much underrepresentation actually exists.

precludes many physically disabled persons from pursuing higher education, but insufficient recent data are available to estimate the extent of the problem.

Choice of Scientific Major. Blacks and Hispanics are underrepresented as college majors in science, mathematics, and engineering. Whites constitute between 78 and 85 percent of the science and mathematics majors.[17] Women choose science majors at lower rates than men, although their enrollments have increased substantially. Thirty percent of the women entering as freshmen in 1984 reported that they intended to major in science and mathematics, compared with 41 percent of the men.[18] These gender differences appear even among equally well-prepared males and females;[19] however, they are less pronounced among minorities than whites. Even though their absolute numbers are far greater, white women are consistently the least represented female group in science majors. Black women constitute a substantially larger share of black science majors than do women of other racial and ethnic groups.[20] In contrast, physically disabled students appear to be somewhat more interested in scientific careers and in pursuing graduate work in science than their nondisabled peers (CHIRP, 1979).

[17]In the fall of 1982, 80 percent of mathematics majors were white, 9 percent were black, and 3 percent were Hispanic. In the same year, 78 percent of the life sciences majors were white, 8 percent were black, and 6 percent were Hispanic. In the physical sciences, 85 percent of the majors were white, 5 percent were black, 4 percent were Hispanic. Seventy-nine percent of the engineering majors were white, 5 percent were black, and 3 percent were Hispanic. Asian students constituted the remaining majors in each field (Commission on Professionals in Science and Technology, 1986).

[18]The most substantial differences occurred in fields other than social science and psychology. For example, 35 percent of males chose majors in biology, computer science, physical science, premedical studies, engineering, or mathematics, compared with only 15 percent of females. Women are least well represented among physical science majors (26 percent are women) and engineering (15 percent) (Commission on Professionals in Science and Technology, 1986).

[19]Of the HSB seniors who scored above the 50th percentile on the HSB achievement tests, nearly 40 percent of the males and less than 15 percent of the females reported majors in scientific fields two years later (Ware and Lee, 1985).

[20]In 1982, for example, 49 percent of the black mathematics majors were women, while 62 percent of the black life science majors were women. In contrast, Hispanic women constituted 55 percent of the Hispanic life science majors; and white and Asian women were each about 48 percent of white and Asian life science majors. Forty-three percent of the black physical sciences majors were women—contrasted with 34 percent of the Asian majors, 35 percent of the Hispanic majors, and 26 percent of the white majors. In engineering, black females were also the highest female group, constituting 28 percent of all black majors. In contrast, women made up 18 percent of the Asian engineering majors, 16 percent of the Hispanic engineering majors, and only 13 percent of the white engineering majors (Commission on Professionals in Science and Technology, 1986). Undoubtedly, the low participation in higher education overall by black males contributes to this relatively strong showing by black women.

Persistence in Scientific Majors. Few data are available to document the persistence of minorities in scientific majors during their college years. However, a comparison of the percentages of black and Hispanic freshmen choosing majors with the percentages of those groups attaining bachelor's degrees in these fields suggests that minorities defect from science at higher rates than their white counterparts. While these data do not reveal whether minority freshmen are switching to other fields or leaving college altogether, they do document further minority losses from the scientific pipeline. Interestingly, however, a recent analysis found that of the students who scored highest on the SAT, minority science majors had higher rates of persistence than whites (Hilton, Hsia, Solorzano, and Benton, 1989). This group, of course, represents only a small fraction of minority college students.

There is conflicting evidence about gender differences in persistence in scientific majors. Most studies have found that men persist at higher rates than women (see, e.g., Corbett, Estler, Johnson, Ott, Robinson, and Shell, 1980; LeBold and Shell, 1980; Matyas, 1986; McNamara and Scherrei, 1982; Schonberger and Holden, 1984, 1987); however, a few studies have found persistence rates of women to be equal or actually higher (DeBoer, 1984a; Gardner, 1976; Greenfield, Holloway, and Remus, 1982; Ware and Dill, 1986). Some of this conflict may be explained by changes in persistence rates over time,[21] but more can be attributed to differences in sample sizes, year during which attrition was measured, and the extent of study controls for ability and prior experience. We can probably be most confident about recent investigations of attrition among large, comparable groups of male and female students. Such studies do suggest that equally well-prepared women defect from science at higher rates than men, particularly during their freshman year.[22]

Degree Attainment and Graduate Study. As discussed above, blacks and Hispanics are significantly underrepresented among those

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[21]A study of Purdue engineering majors found that in the 1960s, the persistence rates of women were half those of men, but since the 1970s, the persistence rates have been nearly equal (Jagacinski and LeBold, 1981).

[22]Ware, Steckler, and Leserman (1985) found that a group of first-year college men and women who were equally predisposed toward a science major (90 percent had indicated an interest in majoring in a scientific field on their college application) and of equally high ability (having nearly identical SAT mean scores) persisted after the first year at different rates. Only 50 percent of the women actually declared a major in science, compared with 69 percent of the men. A follow-up study of this group, however, suggests that gender differences in attrition may be less pronounced after the first year of college, since matched pairs of these students who persisted into their second year showed no gender differences in attrition (Ware and Dill, 1986). In another recent study, the female majors were actually found to be better prepared than the males (Schonberger and Holden, 1987).

earning bachelor's degrees in science and mathematics. These minority college graduates do not continue in graduate school at the same rates as whites, and those in scientific fields constitute about 1 percentage point less of their proportion of undergraduate majors.[23] Consequently, both the failure of blacks and Hispanics to acquire the necessary undergraduate preparation and the failure of those who pursue graduate study to concentrate in these fields contribute to their underrepresentation among the population attaining graduate degrees in science. Black males experience the greatest overall difficulty attaining the necessary preparation for science careers.

Women as a group, unlike minorities, are not negatively affected by overall lower rates of bachelor's and master's degree attainment (they earned slightly more than 50 percent of these degrees overall in 1986). Like minorities, however, they are constrained by lower rates of attaining scientific bachelor's degrees, lower rates of doctoral-level participation generally (they earned 36 percent of the doctoral degrees in 1986), and lower rates of selecting scientific majors in graduate school (NCES, 1988).

ACHIEVEMENT, OPPORTUNITIES, AND CHOICE

Where trend data are available, we find some evidence that all of the patterns described above may be changing. The achievement gap between blacks and whites, for example, has narrowed steadily over the past several years, as has that between females and males. The finding that gains have been largest among the youngest children suggests that these trends may continue. Other data suggest that girls are increasingly participating in high school mathematics and science courses. As yet, however, the prevailing patterns of underrepresentation among these groups have not been altered significantly. And for minorities, in particular, the magnitude of achievement and opportunity differences suggests that it will be difficult to fundamentally alter this pattern.

WHY THESE DIFFERENCES?

The most obvious approach to increasing the participation of women, minorities, and disabled people is to determine the reasons for

[23]In the fall of 1986, blacks constituted 3 percent of the full-time graduate students in all fields of science and engineering; Hispanics, 3 percent; and whites, [illegible] percent (National Science Foundation, 1988).

the discrepancies in achievement, opportunities, and choices, and then develop policies and programs to eliminate or minimize them. Considerable research has been devoted to doing just that.

To summarize the vast and disparate body of studies on participation, we have divided this work into three categories: (1) studies of individual influences, i.e., cognitive abilities and attitudes; (2) studies of schooling factors; and (3) studies of societal factors. The individual and societal factors are not likely to be altered directly by education policy, but policymakers need to understand them because they are linked to students' experiences at school. Moreover, it is in the nexus between student characteristics and schooling opportunities that *alterable* influences on unequal participation are likely to be found. All three domains, then, should be considered by policymakers and educators as they frame interventions to increase participation and by researchers who conduct policy-relevant studies.

Several caveats must be noted about the research as a whole. First, some questions have received a great deal of research attention, while others have received almost none. For example, extensive effort has been devoted to identifying factors related to women's participation in mathematics; fewer studies have considered influences on their science participation; and even fewer have addressed factors related to minority participation in either field. No serious study has been conducted on factors related to the participation of physically disabled students. A second, related caveat is that many studies of minority participation have been hampered by inadequate samples that have required researchers to aggregate data across minority groups or look at only one group—typically, blacks. Findings based on the lumping together of several groups may provide an inaccurate portrayal of the experiences of any one group. Few studies have examined subgroups of minorities separately, and few integrated studies of race and gender have been performed.

Third, most study designs have been inadequate for ascertaining the determinants of unequal participation. Most work has focused on documenting associations among variables thought to be related to participation. While this work provides substantial insight into how groups differ, it tells little about the *causes* of race- and gender-related differences. Moreover, in the absence of any accepted theory about how gender or racial and ethnic differences are produced, the research on patterns of relationships fails to reveal much about the possible importance of those relationships.

Finally, as detailed above, three interrelated factors appear to be critical to the progress—or lack of progress—of various groups through the educational pipeline: opportunities to learn mathematics and science; achievement in these subjects; and choices about whether to pursue study in scientific fields. While a number of analysts and researchers have acknowledged the importance of one or more of these dimensions, and a few have considered relationships among them (e.g., Berryman, 1983; Chipman and Thomas, 1984; Peterson and Fennema, 1985), little theoretical or empirical work has investigated how these factors work together or has attempted to disentangle the relative contribution of each to participation. Because of these rather substantial gaps in the literature, there are few definitive answers to questions of why different groups of students achieve at different levels, what roles schooling opportunities play in achievement, or why some groups tend not to take advantage of the schooling opportunities they have available to them.

These issues will be revisited in the final section of this report.

IV. POSSIBLE CAUSES AND CONSEQUENCES: COGNITIVE ABILITIES AND ATTITUDES

Group differences in individual attributes have been studied as potential contributors to race and gender-linked differences in achievement levels and persistence. These individual attributes fall roughly into two domains, cognitive and affective. Cognitive abilities are seen by most researchers as prerequisite to students' achievement and to the learning opportunities that school personnel decide are appropriate for them. Most researchers hypothesize that affective factors are most related to whether students choose to pursue and persist in science study, although considerable research has also investigated whether and how affective factors and achievement are linked.

COGNITIVE FACTORS

Race and Cognitive Ability

For the past 25 years, considerable attention has centered on the intellectual capacities of economically and socially disadvantaged children. The main question that has driven this discussion is whether disadvantaged children who are entering school possess the basic intellectual abilities that are necessary for success in academic work. Most theorists have focused on the issue of whether impoverished home environments stunt intellectual growth and handicap children with fundamental cognitive deficits (see, e.g., Hunt, 1969). Because many blacks and Hispanics are economically disadvantaged, this work is relevant to the present study. Other research, such as investigations of the question of racial differences in intelligence, has been more directly related to minorities (see, e.g., Jensen, 1969).

Most of the discussion of possible cognitive deficits has been based on evidence about differences in aptitude and achievement as measured by standardized tests of cognitive abilities learned at school, rather than on direct research into these abilities. Consequently, while there is considerable evidence that blacks and Hispanics as a group do less well than whites on cognitive tests at school, little solid evidence exists to support theories of basic cognitive deficiencies of minorities or to assess the effects on achievement and persistence of any deficits that might be found. Therefore, it is reasonable to conclude (as many theorists have) that there is no empirical basis for the hypothesis that racial or socioeconomic groups differ in basic cognitive processes (see reviews by Cole and Scribner, 1974; Ginsburg and Russell, 1981).

In one of the few rigorous studies of this issue, Ginsburg and Russell (1981) assessed the cognitive abilities of preschool and kindergarten children thought to be associated with later mathematics abilities and achievement, e.g., early counting, enumeration (saying how many objects are in a display), conservation, and determining which display has more objects than others. In the sample studied by Ginsburg and Russell, whites as a group never outperformed blacks on tasks measuring these abilities, and those race effects that were found were related to SES. That is, lower socioeconomic groups performed at a lower level than middle-class children on four of seventeen tasks. On two of these tasks, however, the differences disappeared in the older children (kindergarteners). Further, three of the four tasks (one of the two in which the difference disappeared, and both of the others) required an understanding of "some" and "more," two difficult verbal concepts. On two other tasks that required the understanding of these terms, no socioeconomic differences were found.

Several conclusions can be drawn from Ginsburg and Russell (although we would have had more confidence if other studies had replicated this work). First and most important, the differences between blacks and whites found later in schooling cannot be attributed to cognitive deficits found early in life (i.e., there are no genetic deficiencies in cognitive ability that preclude sophisticated mathematical understanding). Neither can impoverished environments be used as an explanation. Although socioeconomic differences do influence performance on some tasks, there are many more tasks on which SES makes no difference. Finally, the finding that many of the group differences disappeared by the time the children reached kindergarten age rules out the possibility that cognitive differences are irreversible, detrimental results of impoverished preschool environments.

While it is not entirely clear that the abilities Ginsburg and Russell studied are linked to later mathematical ability, or that the results found in this particular sample generalize to the nation, this work provides probably the best empirical evidence available about racial differences in basic cognitive abilities prior to schooling.

Culture, Language, and Cognitive Style

Investigations of the effects of differences in cognitive style, especially field-dependence—i.e., being strongly influenced by the context in which knowledge and skills are embedded—and field-independence, on mathematics performance usually view these differences as cultural in origin. Mexican-Americans and women are often depicted as prototypical of field-dependent learners. Some theorists have suggested that lower Hispanic achievement in mathematics might be explained by a preference for more wholistic and less abstract learning conditions, which are not typically found in mathematics classrooms (Ramirez and Castaneda, 1974; Valverde, 1984). While few studies have explored this theory, Kagan found that field-independence was positively related to mathematics performance of both Hispanic and Anglo children (Kagan and Zahn, 1975; Kagan, Zahn, and Gealy, 1977).

Studies of the potential influence of primary language on students' mathematics and science performance have generally found that language facility is related to performance. Hispanic students, especially those whose primary language is Spanish, have been found to be lower achievers in mathematics and science (McCorquodale, 1983; Cuevas, 1984), but these results must be viewed with caution, since few of the studies have controlled for confounding effects of social class on the language-achievement relationship (Lockheed, 1985).

Gender and Cognitive Ability

Gender differences in cognitive ability (spatial visualization ability, in particular), their causes, and their consequences for achievement (especially in mathematics) have been more thoroughly investigated. The nature and findings of these studies are complex and varied, so only a brief overview of this work is given below.

Some studies have found male superiority on spatial visualization tasks (e.g., Brush, 1980; Fennema and Tatre, 1985; Maccoby and Jacklin, 1974), while others have found no gender differences (Linn and Peterson, 1985; Newcombe, Bandura, and Taylor, 1983). Analysts have suggested that these mixed findings can be explained by the fact that gender differences exist only on some of the many types of spatial abilities (e.g., Linn and Peterson, 1985). Ginsburg and Russell (1981) considered a wide range of cognitive abilities, including spatial visualization, and found that preschool and kindergarten boys did not outperform girls on any of the tasks (Ginsburg and Russell, 1981).

A second line of work has generated considerable controversy about whether the gender differences in spatial ability that have been found reflect biologically based differences or differences in childhood experiences and socialization of boys and girls (see Linn and Peterson, 1985, for a review). Some proponents of biological differences suggest that prenatal hormones may play a part, or that differences at puberty may be important (see Crockett and Peterson, 1984, for a review). At this point, however, neither the biological nor the environmental position is supported by unequivocal evidence. Most responsible analysts hold that biological factors are only one of many types of possible influences, and their effects (if any) on spatial ability may be relatively small (see Crockett and Peterson, 1984).

Third, the possible relationship between spatial ability and gender differences has also been hotly debated. While a number of scholars have found a correlation between the two (see Fennema and Sherman, 1977), others (e.g., Benbow and Stanley, 1982) have suggested that the relationship helps to *explain* gender differences in mathematics achievement. However, most researchers conclude that studies attempting to link visualization and mathematical skills have been inconclusive at best (e.g., Fennema, 1984). Few researchers have directly tested the relationship or collected the longitudinal data necessary to establish causation. Moreover, recent meta-analyses of the literature to date have concluded that the relationship itself has insufficient empirical support (Chipman, Brush, and Wilson, 1985; Linn and Peterson, 1985).

A recent reanalysis and synthesis of studies of gender differences performed over the past 20 years makes most of these debates moot: Linn and Hyde (in press) report that gender differences in mathematics and science abilities have dwindled to almost nothing over the past 20 years. While one sex difference remains (males mentally rotate figures more rapidly), girls' poorer performance can be remedied with training. Most important, growing numbers of solid theoretical and empirical studies are demonstrating that cognitive skills can be learned (Brown and Campione, 1982; Sternberg, 1983; Derry and Murphy, 1986) and that both girls and minorities can acquire them (Connor and Serbin, 1985; Ginsburg and Russell, 1981). Thus, even if important group differences in cognitive abilities do exist, they may not necessarily be *unalterable.* That is, interventions can be constructed to overcome these differences and, potentially, the achievement disparities they cause.

AFFECTIVE FACTORS

Several studies have investigated the possible influence of a variety of attitude, motivation, and self-perception factors on the achievement and participation rates of minorities and women. Speculation about the relevance of these factors arises from the theory that individuals pursue areas they value and in which they expect success (see, for example, Chipman and Thomas, 1984). Support for the potential importance of affective factors also comes from analyses suggesting that a primary reason for the underrepresentation of women in science is that women *choose* not to pursue study and careers in scientific fields.

Hypothesized affective factors underlying women's and minorities' lower achievement and participation in quantitative fields include group differences in relative interest in "people" and "things"; liking for mathematics and science; perceived utility of mathematics and science; stereotyping of these subjects as the purview of white males; and confidence in abilities. Some of these factors have been researched extensively in relationship to women and mathematics; less attention has been given to their role in women's participation in science; and even less has been focused on minorities in either field. Most analyses have been correlational, and many are based on rather small sample sizes. In general, then, conclusions about the influence of affective factors remain tentative.

Interest and Liking

Many studies have suggested that girls and minorities show a greater interest in "people," while white boys are more attracted to "things." These early interest patterns appear to have some connection to unequal rates of participation in quantitative fields of study (for example, they may influence choice of college major) (Chipman and Thomas, 1984; Ware and Lee, 1985). Some analysts reason that because mathematics, science, and technology are generally taught as abstract and disconnected from people, these subjects are more appealing to white males than to women or minorities. This analysis is consistent with considerable past evidence that black college-bound male students (Sewell and Martin, 1976) and black college men (Hager and Elton, 1971) show proportionately less interest in science than in service professions, compared with their white counterparts. However, there is virtually no evidence directly linking these preferences with participation, and the recent finding that black and white SAT takers express nearly equal interest in science majors makes earlier findings suspect.

Other evidence (and common sense) suggests that students—regardless of race or gender—are more successful in subjects they like (Antonnen, 1969; Bassham, Murphy and Murphy, 1964; Schofield, 1982). Thus, those who like mathematics and science choose to take mathematics courses (Brush, 1980) and select science majors in college (Ware and Lee, 1985). A number of researchers have investigated race and gender differences in "liking" mathematics and science as possible influences on participation in these areas. Analyses of both national data and small-scale studies have found that boys express more positive attitudes about mathematics than girls do (Sherman, 1980; Sherman and Fennema, 1977). NAEP data reveal that gender differences in attitudes toward science show up in 9-year-olds, 13-year-olds, and 17-year-olds. Moreover, 9- and 13-year-old girls expressed more negative attitudes toward science in 1982 than their counterparts had 6 years earlier (Hueftle, Rakow, and Welch, 1983). The 1986 NAEP data show that these negative attitudes have persisted (Mullis and Jenkins, 1988). Finally, a recent study by Zimmerer and Bennett (1987) found gender differences in California 8th grade students' responses about enjoying science and science-related activities. Both boys and girls were enthusiastic about doing science experiments in science class, but boys were generally more excited about this and other science activities, both in and out of school.

Evidence about the overall relationship between liking science and achievement in science courses is not inconsistent with the speculation that girls may do less well because they like these subjects less (Armstrong, 1980). Additionally, findings that college-age women who persist in science majors enjoy their science classes more than switchers (Ware and Dill, 1986) suggests that within-gender differences in liking may be linked with participation.

However, there is an important reason for skepticism about the effects of liking science on achievement and participation. Almost none of the work in this area has attempted to establish a direction of causality between liking and achievement. And although there is some evidence that changed attitudes toward mathematics accompany and sometimes precede changes in girls' achievement (Fennema and Sherman, 1977, 1978), it would not be surprising to find that doing well in mathematics and science is also a precursor to more positive attitudes. This is especially likely, since gender differences in liking science are less pronounced among high-achieving students (Matthews, 1980).

Also contrary to some theories about interest in people vs. things, black students tend to be as enthusiastic as whites about science and mathematics, and a number of studies (including NAEP) have found that black students express the most positive attitudes of any group (Hueftle, Rakow, and Welch, 1983; Matthews, 1980; Zimmerer and Bennett, 1987). Moreover, black females are often more positive than their white counterparts (Zimmerer and Bennett, 1987; Dossey et al., 1988). These studies make the existence of a direct or simple relationship between liking science and mathematics and doing well in these subjects doubtful, since liking does not appear to lead to high achievement and participation by minority students.

Perceived Utility

Some analysts have suggested that students who do not enjoy mathematics may still persist if they believe that it will be useful to their later careers. Following this logic, it might be hypothesized that women and minorities take only the minimum required mathematics courses because they do not perceive mathematics as useful to their future career goals (Reyes, 1984). This hypothesis is supported by considerable evidence that students' perception of the usefulness of mathematics is an important predictor of future mathematics course-taking (Armstrong, 1985; Hilton and Berglund, 1974; Pedro, Wolleat, Fennema, and Becker, 1981; Sherman, 1980; Sherman and Fennema, 1977) and persistence in college majors for both sexes (Ware and Dill, 1986).

The link between perceptions of usefulness and participation is given further support by findings that boys see mathematics as useful more than girls do. Several studies have found this difference as early as 7th grade (Brush, 1980; Eccles, Adler, Futterman, Goff, Kaczala, Meece, and Midgley, 1985; Fennema and Sherman, 1977; Hilton and Berglund, 1974; Wise, Steel, and MacDonald, 1979). Perceptions of the usefulness of mathematics have also been linked to gender differences in achievement at the middle and senior high school level (Armstrong, 1980; Fennema and Sherman, 1977, 1978), and to women's decisions to study mathematics in college (Berryman, 1983).

The small body of research exploring possible links between perceived usefulness and minority participation is equivocal. Some studies find that minority students have lower expectations than whites about the future usefulness of mathematics in jobs, schooling, or everyday life (e.g., Matthews, 1984). Other studies find that minorities hold higher expectations than whites that science will be important in their careers (e.g., Zimmerer and Bennett, 1987). Neither finding, however, sheds any light on the relationship between perceived usefulness and minority students' achievement or participation.

Stereotyping of Mathematics and Science

Recent studies have found that substantial numbers of students believe that mathematics is more useful for males than females (Eccles et al., 1985), that studying science is more important for boys, and that boys understand science better (Zimmerer and Bennett, 1987). This sex stereotyping has been found to occur as early as the primary grades (Vockell and Lebonc, 1981). Some analysts also have suggested that those girls who see mathematics and science (particularly physical science) as "masculine," and therefore not particularly relevant to their own lives, may be less motivated to do well in these subjects (Stage, Eccles, and Becker, 1985). And some empirical evidence does support the hypothesis that the perception of mathematics as masculine relates to girls' lower rates of mathematics coursetaking (Lantz and Smith, 1981; Sherman, 1980) and lower levels of achievement (Dwyer, 1974; Fennema and Sherman, 1978; Sherman, 1980). Further, girls have been found to lower their expectations for success at tasks that are seen as masculine (Lenney, 1977).

Nevertheless, these findings should be interpreted with caution. The overall amount of sex stereotyping of mathematics among girls appears to be rather limited (Brush, 1980; Fennema and Sherman, 1977; 1978; Zimmerer and Bennett, 1987), and the correlation between stereotyping and participation is quite low (Lantz and Smith, 1981). Furthermore, sex stereotyping may be changing rather rapidly. Boys and girls may not stereotype equally: While many female students are convinced that mathematics is open to everyone, boys more often see mathematics as masculine and place girls in more traditional roles (Fennema and Sherman, 1977; 1978). This finding may be important, since, as discussed below, the support of significant others appears to influence girls' participation in mathematics (Lantz and Smith, 1981), and the opinions of male peers are likely to be seen by them as significant.

Girls, particularly Hispanic girls, may also be deterred by what they see as both current and future social costs to women who aspire to mathematics and science careers (Chipman and Thomas, 1984; McCorquodale, 1983). One such cost is anticipated conflict between male-dominated careers and child raising. Some studies suggest that women college students who remain in science-oriented majors have nontraditional views of sex roles, in that they anticipate delegating more household responsibility to their future spouses (Matyas, 1985). Similarly, college sophomore women majoring in science in 1982 gave a lower priority than other women to future family and personal life (Ware and Lee, 1985). These findings also suggest that some women may expect science and family to conflict later in life.

The possible influence of stereotyping and perceived role conflicts is reinforced by findings from programs that have successfully used female role models to increase girls' participation in mathematics (Brody and Fox, 1980; MacDonald, 1980; Tobin and Fox, 1980). These programs have attempted to compensate for girls' lack of exposure to adult women who are engaged in mathematics and science, or who successfully juggle career and home responsibilities, or who are confident about their mathematics abilities (see Stage et al., 1985, for a review). Other support comes from findings that exposure to female role models is related to women's choice of science majors (Matyas, 1986) and their grades in college science courses (Boli, Allen, and Payne, 1985).

Less is known about the possible effects on minority achievement and participation of stereotyping of science, mathematics, and technology as "white" domains. There is some evidence of negative stereotyping effects (Matthews, 1984), but the relationship between stereotyping and minority achievement has not been fully explored.

Confidence

Extensive research suggests that children's attribution of their success to their own ability and efforts contributes to their persistence and performance in school and to their efficacy (for reviews, see Stipek and Weisz, 1981; Weiner, 1977). More specifically, children's belief in their ability appears to be a strong predictor of performance on mathematics tasks (Schunk, 1981, 1982). Confidence in mathematics ability has been linked to the selection of science-based college majors (Betz and Hackett, 1983) and to the taking of elective college courses in mathematics and science (DeBoer, 1984a, 1984b; Sherman, 1982, 1983). Negative links have also been established between "math anxiety" and math achievement among students from grade school to college (see Reyes, 1984).

While boys and girls have been found to be equally motivated to do well, girls appear to be less confident that their efforts will result in successful performance (see, for example, Lantz and Smith, 1981). Girls have also been found to give up more easily than boys after experiencing failure or difficulty. They appear to be especially insecure about their prospects for success on tasks they see as requiring high ability, and they exhibit less persistence on unfamiliar or difficult tasks. The expectations for success of even very able girls appear to be more fragile than those of boys. These findings have led to the suggestion that girls may have less confidence than boys in their ability to achieve generally (see Hudson, 1986, for a review of this literature).

Boys are more confident about their abilities in mathematics than are equally able girls (Fennema and Sherman, 1977, 1978; Linn and Hyde, in press), and they exhibit more confidence while solving problems on mathematics achievement tests (Hudson, 1986). Moreover, boys report that they expend less effort to do well in mathematics, and they have higher expectations for further success than girls with similar past mathematics performance (Eccles et al., 1985; Matthews, 1980). These sex differences in mathematics confidence emerge at the junior high school level (Brush, 1980; Eccles et al., 1985; Fennema and Sherman, 1977; Fox, Brody, and Tobin, 1980), just before enrollment and achievement differences begin to appear, and just about the time important gender-role decisions are being made.

The possible negative effects of girls' lower expectations about success in mathematics are compounded by other evidence that girls more often attribute their failures to lack of ability and their successes to effort. One recent study found that male college students tended to attribute their difficulties to external factors, e.g., the inherently difficult nature of the course material or poor instructors, whereas women tended to place the blame on their own perceived inadequacy (Ware, Steckler, and Leserman, 1985). However, DeBoer (1984b) studied freshmen enrolled in science courses at a small, selective liberal arts college and found no gender differences in attributions of success or failure to external or internal factors. However, selection bias in the sample may account for this contradictory finding.

Finally, girls tend to be more subject to "math anxiety" than boys (e.g., Betz, 1978; Reyes, 1984; Stage et al., 1985). Moreover, to the extent that students (girls, particularly) believe that mathematics gets progressively harder, their math anxiety increases (Brush, 1980). Linn and Hyde (in press) found that consistently lower levels of confidence among girls have not diminished over the past 20 years.

Important links between confidence and girls' mathematics achievement have been found both in analyses of national data (Armstrong, 1980) and in smaller, well-controlled studies of precollege students (Fennema and Sherman, 1977, 1978). Moreover, the relationship appears to grow stronger as girls get older (Armstrong, 1980), as does the relationship between lower levels of confidence and lower rates of mathematics coursetaking (Armstrong and Price, 1982; Sherman, 1980; Stage et al., 1985) and persistence in science majors as college students (Ware and Dill, 1986).

As with other affective factors, we know far less about race- and ethnicity-linked differences concerning science and mathematics. Some early evidence suggests that blacks have less confidence about their general ability than do whites (Wylie, 1963), and Hispanic community college students have been found to be far less confident than their white peers (Rendon, 1983). Black males, in particular, appear far less certain about their ability to learn enough mathematics to become scientists, engineers, or mathematics teachers (Matthews, 1980). However, 1982 NAEP data show black 13- and 17-year-olds to be the most favorably disposed toward science careers of any group (Hueftle, Rakow, and Welch, 1983). And recent California Assessment Program data show all minority groups among the state's 8th graders indicating more often than whites that science will be important to their future careers (Zimmerer and Bennett, 1987). In addition, high-ability minority students (those scoring 550 and above on the SAT) are more likely than whites to choose quantitatively based fields of study (Hilton et al., 1989). However, these high levels of interest in science careers tell little about students' confidence that they can actually attain these goals.

CONCLUSIONS: THE INFLUENCE OF ABILITIES AND ATTITUDES

Despite the extensive work that has been conducted on group differences in cognitive abilities and attitudes, and on the potential influence of these differences on student achievement and participation, few conclusions can be drawn about the causes of these differences or their effects on students' opportunities, achievement, and choices to pursue science.

Despite obvious racial differences in mathematics and science achievement, few differences in basic cognitive abilities or attitudes among racial and ethnic groups have emerged that help explain these differences. Indeed, blacks have been found to hold the most positive attitudes of any group about science—e.g., they find their science classes more interesting and express a more positive attitude toward science as a career (Hueftle, Rakow, and Welch, 1983). However, their lower levels of achievement cast doubt on the proposition that positive attitudes lead to higher achievement or more opportunities to participate. A more plausible hypothesis is that positive attitudes can have an effect on minority students' behaviors in science and mathematics only if they are expressed in the context of actual science experiences. For example, blacks who expressed interest in science projects as children and participated in science clubs in high school were found more likely to choose science as a college major (Thomas, 1984; Snelling and Boruch, 1972). NAEP data and other findings indicate that minorities as a group have fewer such opportunities. However, the paucity of research on minorities probably best explains the lack of understanding of the role of individual factors on black and Hispanic participation.

While no important gender differences have been found in cognitive abilities, women's attitudes are considerably less positive, which may provide a plausible explanation for the failure of girls to achieve as well as they get older, and for their choice not to pursue scientific fields. Even though the studies noted above are largely correlational, they certainly suggest that girls like science and mathematics less than boys, see these subjects as less relevant to their futures, and feel less confident about their ability to succeed in them. Interventions to improve girls' attitudes may thus be one possible way to increase girls' achievement and willingness to pursue the science and mathematics opportunities that are available.

However, we must be cautious about jumping too hastily to the conclusion that gender differences in achievement and participation are caused by attitudes. A comprehensive meta-analysis of the correlational literature linking student affect, ability, and science achievement (Steinkamp and Maeher, 1983) found little overall relationship between attitudes and achievement. Moreover, the connections between gender differences in science attitudes and achievement are anything but clear-cut. Perhaps even more important, *overall* gender differences in attitudes, abilities, and achievement in science appear to be quite small, and additional variables must be found to explain the much larger gender differences in adult participation.

No single factor, thus, has been found likely to be very powerful in explaining participation differences. The inconclusive findings summarized above highlight weaknesses in much of the current research, including an overreliance on correlations among single variables, the use of varying definitions of attitudinal variables, the difficulty of measuring attitudes, and the near absence of empirical work based on models or theories that suggest how a variety of factors (including attitudes) jointly influence achievement and choices.

The most useful and revealing models are those that incorporate other factors (e.g., prior achievement, schooling experiences) as well as attitudes to explain differences in achievement. For example, Kulm's (1980) model of attitude-behavior relationships suggests that attitudes may operate differently among students of differing achievement levels or may have different effects in different learning situations. Peterson and Fennema's (1983) model of gender differences in mathematics achievement describes a chain of influence from external factors (e.g., classroom conditions) and attitudes (including confidence, perceived usefulness, attribution for success and failure) to autonomous learning behaviors (including choosing tasks to work on, working independently, and persisting) and, finally, achievement.

The usefulness of models has been demonstrated in evaluations of the influence of attitudes on gender differences in high school mathematics coursetaking. Research in this area (e.g., Eccles et al., 1985, 1986) provides considerably more insight into the role of attitudes in a complex process of decisionmaking. Chipman and Thomas (1984) found that current research provides substantial support for the conclusion that attitudes become central once achievement is controlled. Differences in interest in mathematics, perceptions of its utility, and confidence are sufficient to explain the differences between males and females of equal achievement levels in their choices to take high school coursework that prepares them for scientific majors.

Among first-year college men and women who are equally predisposed toward science majors and of equally high ability, fewer women than men appear to persist after the first year of study (Ware, Steckler, and Leserman, 1985). Also, although women science majors had higher mean scores on both SAT verbal and quantitative subtests and ranked higher in their high school graduating classes, they defected from science in greater percentages than their male peers (Schonberger and Holden, 1987). Finally, a greater proportion of female science majors in the HSB sample switched to other fields, even though they had higher overall grades during their first two college years than did the men (Ware and Lee, 1985). When other factors are taken into consideration, then, attitudes may play a critical role in high-achieving women's defection from (or rejection of) science.

In short, we have considerable evidence that women are more negative than men about science and about the role it might play in their future lives. While there is little evidence that these attitudes *cause* the lower levels of achievement and participation that they are often linked to, they may deter high-achieving girls from persisting in science and mathematics courses and career plans. In contrast, minority students generally express positive attitudes about science and mathematics, but these attitudes are not paralleled by high levels of achievement and participation. These attitudes most likely have a conditional effect—that is, among students with low levels of achievement and fewer learning opportunities (some women and most minorities), positive attitudes will be insufficient to promote achievement or encourage students to seek further study of science and mathematics. Students who achieve at high levels and who have ample opportunities to learn science and mathematics still need positive attitudes to choose and persist in scientific study.

The studies reviewed above do not consider the influence of school and classroom conditions on gender- and race-related differences. Possible school influences are considered in the next section.

V. POSSIBLE CAUSES AND CONSEQUENCES: SCHOOLING EXPERIENCES

This section examines how schooling experiences differ for girls, minorities, and disabled students and how these differences may influence students' learning opportunities, achievement, and decisions to study science. Four aspects are investigated: (1) access to educational resources, (2) access to guidance and encouragement from school adults, (3) access to mathematics and science content, and (4) teacher expectations and classroom teaching strategies. While the likely effects of schooling experiences on opportunities to learn science and mathematics are fairly straightforward, there is insufficient evidence to establish that these experiences cause discrepancies in students' achievement and choices. Nevertheless, the fact that gender and race-linked achievement differences increase with years spent in school provides a noteworthy signal that school experiences may, at the least, interact with students' backgrounds and attitudes in ways that contribute to these growing discrepancies. Again, there is very little available data on the science and mathematics experiences of physically disabled students.

ACCESS TO EDUCATIONAL RESOURCES

Funding Levels

State and federal funding for public education is particularly critical for non-Asian minority students. As a group, they are poorer than other students, and they are less likely to have access to science and mathematics experiences outside of school. Many minority families cannot afford to supplement school experiences with learning opportunities in the private sector (e.g., enrolling in museum classes, engaging the services of a tutor, or purchasing a home computer), and minority students typically have fewer educational resources in their homes (Ekstrom, Goertz, and Rock, 1988).

Most black and Hispanic minorities attend schools in central cities, where the competing demands for tax dollars are great. In 1983, 71 percent of blacks and 58 percent of Hispanics were reported to live in inner cities (American Council on Education, 1983). In addition, the *proportion* of minority enrollments in large-city school districts has increased dramatically in the past 15 years—in some cases, it has doubled. By 1982, in at least 15 of the largest districts, minority enrollments were greater than 70 percent (NCES, 1985a), and current projections suggest that these trends will continue.

In most of these communities, the levels of property wealth and personal income are low, as are per-pupil schooling expenditures. This situation has persisted even in those states where school finance reforms have attempted to equalize schooling resources (Carroll and Park, 1983). Per-pupil expenditures between some neighboring high- and low-wealth districts differ by as much as a factor of two (see Catterall, 1989b). Unequal funding patterns mean that poor, minority children have less access than their more advantaged counterparts to well-maintained school facilities, highly qualified teachers, small class sizes, and instructional equipment and materials—important educational resources that funding dollars can buy.

Moreover, poor minority children have been more negatively affected than others by recent changes in educational funding policies. The reduction of federal assistance to education during the past five years, including that for compensatory programs and desegregating school districts, has reduced the resources available to these children (Levin, 1986). Districts that cannot be integrated because too few white students are available are not eligible for desegregation funding that could be used to establish science or mathematics magnet schools. Changes in the way federal funds are distributed have further diminished programs and services for disadvantaged children. The Educational Consolidation and Improvement Act (ECIA) of 1981 lessened the regulation and monitoring of Chapter 1 compensatory funds with respect both to targeting aid for particular populations and ensuring comparable spending in target and nontarget schools. Additionally, by clustering the Emergency School Assistance Act program, aimed at assisting desegregating school districts, together with a number of other programs into enrollment-based block grant funding, ECIA further reduced funds and programs for urban schools and minority children (Darling-Hammond, 1985).

At the state level, decreased public willingness to provide support for schooling (best exemplified by the "tax revolt" that began with the passage of California's Proposition 13 in 1978) has led to substantially fewer dollars available for education generally. Community groups have offset these reductions in many advantaged school districts by establishing educational foundations to raise additional funds. These, however, are not the districts where most poor, minority children live. Finally, declining enrollments in some urban districts have further reduced available local tax dollars. Many urban districts have cut back on the maintenance of facilities and purchases of textbooks and equipment; and some have been forced to close schools altogether. Even though important recent legislative changes have tipped funding priorities back toward need-based criteria, and many states have increased funding in conjunction with educational reforms, few urban districts have been able to recoup their losses from the previous decline. Spending for science-specific resources, including the equipment and supplies necessary to provide science laboratory experiences, participation in museum-sponsored programs and activities, and the purchase of up-to-date science texts, is often the first budget item to be curtailed. In short, minority students are likely to have less access to schooling resources that provide important opportunities to learn science.

Teacher Resources

Many minority and poor students have less exposure to high-quality teaching because predominantly minority and poor schools are less able to attract or retain qualified and experienced teachers. Disproportionate numbers of poor and minority students are taught during their entire school careers by the least-qualified teachers, because of high teacher turnover, larger numbers of misassigned teachers, and classrooms staffed by teachers holding only emergency credentials (California Commission on the Teaching Profession, 1985). Nationally, in 1983, there were three times as many unfilled teaching vacancies (including positions that were withdrawn or for which a substitute was hired) in central cities as in other types of districts (NCES, 1985a).

Gaps in the distribution of teacher quality may be particularly critical in mathematics and science, in view of the national shortage of qualified science and mathematics teachers, especially teachers of physical science. In 1981, more than half of the newly hired teachers in these fields were either not certified or lacked the qualifications for certification in the courses they were to teach (NCES, 1985a). By 1984, there had been a 67 percent decrease in the number of science and mathematics teachers who graduated from college during the previous 12 years, and as many as 30 percent of the teachers teaching science and mathematics at the secondary level may have been unqualified or underqualified to do so (Johnston and Aldridge, 1984). More recent data suggest that most science courses are taught by teachers who specialize in science, although perhaps not in the specific subject taught (National Science Teachers Association, 1987). Nevertheless, suboptimal teaching conditions—canceled courses, increased class sizes, teaching misassignments, and the use of substitutes—in mathematics and science are far more likely to exist in inner-city schools.

While there is little hard evidence on the effects of teacher quality differences on students' achievement or choices, few disagree that teachers are an important part of the educational process. Teachers who are well-prepared to teach and knowledgeable in the subjects that students are expected to learn are an important prerequisite to student learning (Darling-Hammond and Hudson, 1989). Thus, a teacher-quality gap among schools serving different student groups is an important dimension of the distribution of educational opportunity.

Science and Math Resources

Differential access to specific mathematics and science resources has also been documented, including inequities in the number of microcomputers available for student use and variations in the ways computers are used for different subpopulations of children (Becker, 1983; 1986; Furr and Davis, 1984; Winkler, Shavelson, Stasz, Robyn, and Feibel, 1984). In 1983, the 12,000 wealthiest schools were four times more likely to have microcomputers than the 12,000 poorest schools (Furr and Davis, 1984). Only about 40 percent of middle schools in low-SES communities had as many as 15 microcomputers, whereas in high-SES communities, two-thirds of the middle schools had at least this number (Becker, 1986). These data echo earlier findings that schools with large numbers of students in the federal free-lunch program are less likely to have computers, calculators, and resource centers (Weiss, 1978).

Smaller percentages of children in elementary schools serving minority children actually use the computers. Moreover, fewer poor and minority schools have teachers who are computer specialists. Thus, these schools are more likely to use their computers for "drill and practice" and less likely to use them for instruction in, for example, computer programming (Becker, 1983; Miura, 1987).

Physically disabled students, too, are restricted in their access to science resources: Only 24 percent of schools have science laboratories suitable for use by physically disabled students (NCES, 1985a).

Girls first experience differences in access to schooling resources at the within-school level. In secondary schools, computers are concentrated in mathematics and science courses and in computer courses with advanced mathematics prerequisites, so girls use computers less frequently than boys (Furr and Davis, 1984). Boys outnumber girls by three to one in their before- and after-school use of computers (Becker, 1986). Moreover, 8th grade boys in California schools report that they use many more science instruments in class (Zimmerer and Bennett, 1987). The most pronounced differences are reported in the use of physical science tools such as power supplies and prisms. Science tools that girls report using more often are biologically oriented; for example, more girls than boys report using microscopes.

Type of College

At the college level, the resources in an institution influence the quality of the students' experiences. Again, black and Hispanic students appear to be more disadvantaged than their nonminority peers. Because more minorities than whites attend two-year colleges, fewer of them are either enrolled in two-year degree programs or transfer to four-year schools, and greater percentages of those attending four-year institutions are enrolled in colleges rather than universities; thus, black and Hispanic students have less access to those institutions with the greatest resources for scientific programs. Moreover, recent cuts in programs providing financial aid to college students have undoubtedly had a disproportionate effect on minorities.

For blacks, however, attendance at a historically black institution may be a factor in obtaining a science Ph.D. A survey of 515 black doctoral scientists who received their degrees before 1974 found that 87 percent had their undergraduate origins in black institutions (Pearson and Pearson, 1985). A more recent study of college juniors in the South found that students in predominantly black four-year colleges were more likely to major in science (Thomas, 1984). However, no discrepancies have been found between the percentages of blacks choosing science majors at predominantly black and white colleges nationwide (Baratz and Ficklen, 1983; Berryman, 1983).

ACCESS TO GUIDANCE AND ENCOURAGEMENT

Counselors and teachers influence students with their expectations, advice, and encouragement. Teachers encourage or discourage future coursetaking and higher achievement through their day-to-day interactions with students and, for women and minorities, by their presence as role models:

> I just hate to see a girl get in over her head. I always try to place students at a level where I know they'll be successful. I mean, wouldn't it be frightful to spoil a beautiful record by doing poorly in a course your senior year? (A woman counselor in her twenties during the 1974–75 school year, as quoted in Casserly, 1980).

Advice and Encouragement

Counselors and teachers can provide encouragement and information about coursetaking options, college entrance requirements, career opportunities, and sources of financial support for college (Chipman and Thomas, 1984; College Entrance Examination Board, 1986). On the other hand, as in the example above, they can also provide considerable discouragement and withhold information. Some evidence suggests that girls, minorities, and disabled students have less access to encouragement and information regarding courses and careers in scientific fields.

Perhaps the most overt differential counseling practice is the continued use in many schools of vocational-interest tests with sex-specific norms for counseling students about career choices and appropriate school preparation (Chipman and Thomas, 1984). Equally discriminatory are counseling practices that steer physically disabled students away from science classes because of counselors' and teachers' beliefs that such students could not function either in a laboratory setting or in a science-related work setting (Malcom, 1985; Stern, 1987).

Most differential counseling practices are more subtle. Poor and minority students appear to have received advice about academic coursetaking, college entrance preparation, and financial assistance (Cicourel and Kitsuse, 1963; College Entrance Examination Board, 1986; Erickson, 1975), but minority and low-SES students in the HSB sample reported less access to guidance counselors. At the same time, researchers found that students with the greatest access to counselors were the most likely to be put in academic tracks that included advanced mathematics and science courses (Lee and Ekstrom, 1987). Thus, the students whose families are least likely to be able to provide academic counseling also appear to be the ones who receive the least advice and assistance at school (College Entrance Examination Board, 1986).

Discouragement sometimes takes the covert form of expectations or attitudes that reflect sex stereotypes (Harway and Astin, 1977). Males have traditionally (although perhaps decreasingly) been expected to perform better in mathematics and have received greater counselor encouragement (Casserly, 1979). They also tend to garner greater praise and reward for achievement (see Stage et al., 1985). Male engineering majors report having received more encouragement to improve technical work skills and to try engineering; they were more often made aware of engineering as a possible career and were informed about courses that would help prepare for such a career (Erickson, 1981).

Other researchers have found that support and information can positively affect girls. For example, Casserly found that teachers who sincerely praise girls and support the value of mathematics for high-pay, high-prestige careers for women have a positive influence on girls' attitudes toward mathematics (Casserly, 1979; Casserly and Rock, 1985).

Role Models at School

It is widely believed that contacts with female and minority science and mathematics teachers will encourage participation among students from these groups. However, while the positive effect of role models is fairly well-documented for women, little evidence exists to either support or refute this effect in regard to minority students.

The evidence about the actual impact of female teacher/counselor role models is mixed. Some studies have found that role models can have a positive influence on girls' attitudes toward mathematics by providing active encouragement (Casserly, 1979; Casserly and Rock, 1985), and other studies suggest that they are influential in the achievement of high-achieving women. A study of Stanford freshmen found that women with female mathematics teachers in high school had somewhat higher mathematics SAT scores. This was not simply a reflection of superior teaching ability on the part of women high school mathematics teachers—no such effect was found for male students. Moreover, nearly three times as many women who had had one or more female role models in high school received A grades in their college mathematics courses than those who had all male mathematics teachers in high school. Finally, only half as many women with positive role models failed to complete chemistry (Boli, Allen, and Payne, 1985). But role models may not be powerful enough to counteract stereotypical views of science fields. Vockell and Lebonc found that the presence or absence of female teachers makes little difference in girls' perceptions of physical science careers as masculine or feminine (1981). However, the absence of such effects may be due in part to the fact that advanced mathematics and all science courses are more likely to be taught by men (Fox, Fennema, and Sherman, 1977; National Science Teachers Association, 1987).

It appears that girls and minorities (and probably the physically disabled as well) may be especially sensitive to the support and example of important adults. The encouragement of teachers and counselors may help them to overcome negative perceptions that mathematics and science have little future utility to them. However, neither the distribution of counseling, information, and encouragement nor their effects on various groups has been adequately studied.

ACCESS TO SCIENCE AND MATHEMATICS KNOWLEDGE

Curriculum Tracking

There is growing evidence that schools' judgments of students' intellectual abilities and achievement play a major role in determining the opportunities students have available to them (Guthrie and Leventhal, 1985; Lee, 1986; Oakes, 1985). These judgments cause the access different students have to mathematics and science knowledge to diverge early in their school careers. In elementary schools, students who appear to be slow in mathematics are often placed in "slow" groups or remedial programs; those who learn more easily are placed in "fast" groups or high-ability classes. At the senior high school level, judgments about students' ability influence decisions about whether a student will take a college-preparatory, general, or vocational course of study. Curriculum track enrollment, in turn, is critical in both course-taking (Lee, 1986; Rock et al., 1984; 1985) and curriculum content, instructional practices, and learning environments (Oakes, 1985). Data from *A Place Called School* (Goodlad, 1984) and *The Underachieving Curriculum* (McKnight et al., 1987), for example, show that students in upper-level mathematics classes focus more on mathematical concepts; those in low-level classes focus almost exclusively on computational skills and mathematics facts.

Track-level differences in content and pace of instruction affect what and how much elementary school students actually learn. Students who are not in the top achievement groups appear to learn less because of these placements (Barr and Dreeben, 1983; Hallinan and Sorenson, 1983; Slavin, 1986), with the result that some students finish elementary school already having had some preparation for high-school mathematics concepts and skills, while others still lack understanding and skill in basic facts and operations.

Tracking also works to the academic detriment of secondary school students who are placed in low-ability classes or non-college-preparatory groups (see reviews by Calfee and Brown, 1979; Esposito, 1973; Findlay and Bryan, 1971; Noland, 1986; Rosenbaum, 1980). National data suggest that students who are initially similar in background and aptitude exhibit increasingly wide achievement differences following placement in higher and lower tracks (Alexander and McDill, 1976; Alexander, Cook, and McDill, 1978; Gamoran, 1986). The net effect appears to be cumulative, since students' track placements tend to be fixed and long-term. Students placed in low-ability groups in elementary school are likely to continue in these tracks in middle schools and junior high schools; they typically are placed in non-college-preparatory tracks in senior high school (Rosenbaum, 1980;

Oakes, 1985). Recent studies provide evidence that at the senior high level, this effect is largely attributable to differences in student coursetaking that result from tracking.

These findings about curriculum tracking raise the possibility that, in their efforts to accommodate differences in ability, schools may actually exacerbate the differences among students by limiting some students' opportunities to learn mathematics and science. These findings are particularly relevant for minorities, since patterns of track placement tend to favor white students.

Course Offerings

The courses offered at high schools also place limits on students' learning opportunities. This obvious conclusion is relevant to participation, since poor and minority students are more likely to attend schools with limited offerings in mathematics and science. For example, in California, the number, size, and substance of courses offered have been found to differ with the composition of schools' student populations: The greater the percentage of minorities, the larger the low-track program; the poorer the students, the less rigorous the college-preparatory program (California State Department of Education, 1984). Further, HSB data show that, nationally, schools serving predominantly poor and minority populations offer fewer advanced courses and more remedial courses in academic subjects, and that they have smaller academic tracks and larger vocational programs (NCES, 1985a; Ekstrom, Goertz, and Rock, 1988). Schools that emphasize vocational and/or general track programs are less likely to offer advanced science and mathematics courses than schools with extensive college-preparatory programs (Matthews, 1984).

Coursetaking patterns also vary with the ethnic makeup of a school's student population. Fewer mathematics courses are taken at schools with substantial black populations than at schools with substantial white populations (Jones, 1984).[1]

Patterns of course offerings are undoubtedly influenced by the lower levels of mathematics and science achievement typically found at predominantly minority schools. Schools respond to those differences with programs they see as educationally appropriate. But lower-track

[1]Recent analyses of HSB data, however, reveal no discrepancies in coursetaking between schools with 10 percent or greater black or Hispanic enrollment and schools with fewer than 10 percent minorities (NCES, 1985b). However, these data are likely to be misleading, since 1980 data show that three-quarters of all black students attend schools where minority enrollments exceed 30 percent (Jones, 1984). Lumping together all schools with 10 percent or more minority enrollment may obscure important differences in course offerings and coursetaking among those schools.

mathematics and science courses may actually limit students' opportunities to learn these subjects, continuing a cycle of restricted content, diminished outcomes, and exacerbated differences between low-track students and their counterparts in higher tracks. Moreover, low-track placement does not appear to overcome students' deficiencies in mathematics and science. It is important to note also that the restricted courses available at predominantly poor and minority schools limit the mathematics and science opportunities of those highly able students who attend these schools. These students may be denied opportunities for which they are prepared simply because of the school they happen to attend.

Coursetaking

Race- and gender-related differences in science and mathematics coursetaking have been detailed above. Considerable evidence supports the influence of lower levels of coursetaking on achievement. The "differential coursetaking hypothesis" has been explored in great detail, particularly since the advent of large databases (HSB and NAEP) that have enabled analysts to correlate coursetaking with students' scores on achievement tests. Other studies suggest that coursetaking critically influences the choice of a quantitative major in college (Sells, 1982) and persistence in that major (Boli, Allen, and Payne, 1985).

Early studies of sex differences in mathematics achievement consistently found male superiority (Fennema, 1984), but because these studies used random samples of females and males enrolled in secondary schools, their male and female populations had taken disproportionate numbers of mathematics courses. Unexplained findings of sex differences are less frequent in studies performed since the mid-1970s, when researchers began to control for students' coursetaking histories (e.g., Fennema and Sherman, 1977, 1978). The most recent analyses suggest that sex-related achievement differences are largely explained by greater coursetaking by boys than girls (Pallas and Alexander, 1983), even when prior mathematics achievement is controlled (Wolfle and Ethington, 1986).

This evidence about coursetaking effects is consistent with evidence that boys' superior test performance is not paralleled by differences in classroom performance levels. When girls do enroll in mathematics courses, their course grades are as high as boys' (Benbow and Stanley, 1982, 1980; DeWolf, 1981; Pallas and Alexander, 1983). Some might argue, of course, that this occurs because only high-ability girls actually enroll in advanced mathematics courses; but NAEP data show nearly equal mean mathematics achievement scores for 13-year-old boys and girls. These NAEP data suggest that only after differential coursetaking patterns are evidenced do girls and boys exhibit different mathematics ability.[2]

Analyses of both NAEP and HSB data show that differences in the number of high school courses taken by black and white students account for a considerable part of the differences in mathematics and science achievement (Jones, 1984; Jones, Davenport, Bryson, Bekhuis, and Zwick, 1986). Analyses of the Longitudinal Study of Youth Labor Force Behavior data have produced similar findings for Hispanics and whites (Moore and Smith, 1985).

But the number of courses taken is not a sufficient explanation for the full impact of coursetaking on either girls or minorities. Minority/white differences are also found in the level or type of courses taken (Jones, 1984; Moore and Smith, 1985). In analyses of HSB data, differences among blacks, Hispanics, and whites in senior year achievement are "fully explained" by achievement differences in the sophomore year and by representation of these groups in different types of mathematics courses. Whites' superior performance is explained by their higher 10th grade achievement and their disproportionately higher rates of enrollment in advanced mathematics classes (Jones, 1985). In high school, too, the level as well as the number of courses taken has been found to be an important factor in subsequent achievement and participation in mathematics and science, with calculus completion a significant predictor of success and persistence in college mathematics (Sells, 1982; Peng, Owings, and Fetters, 1982).

Findings that coursetaking is critical to performance should come as no surprise, since coursetaking is the most powerful school-related predictor of achievement, particularly in mathematics (see, for example, Welch, Anderson, and Harris, 1982). Science coursetaking has considerably smaller effects on students' science achievement test scores, but this is to be expected, since mathematics achievement is far more critical in students' eligibility to pursue science-related majors in college.

Precollege coursetaking is clearly a key to discrepancies in science and mathematics participation, but the precursors of differential course- taking are different for minorities than for girls. For women, choices appear to be the critical factor. Until high school, girls as a group achieve in mathematics at levels equivalent to boys. While current analyses do not provide definitive conclusions, it is probably

[2]These data do not explain the disproportionate percentage of boys among 7th grade early SAT takers who attain exceedingly high scores (Benbow and Stanley, 1982). One might speculate, however, that these boys may have had greater encouragement and out-of-school mathematics experiences.

true that relatively equal numbers of both sexes are qualified for advanced mathematics and science course sequences as they enter high school and complete minimum college-entrance requirements. However, girls who are academically qualified more often do not choose to take more advanced mathematics and science courses. Blacks and Hispanics, in contrast, are most affected by academic deficiencies. On average, these groups fall behind in achievement early in their school careers, are less likely to have learning opportunities that prepare them for advanced work, and less often qualify for advanced high school courses. These differences suggest that changing coursetaking patterns will be far more difficult for minorities than for girls.

TEACHER EXPECTATIONS, TEACHING STRATEGIES, AND CLASSROOM ACTIVITIES

What students actually experience in their science and mathematics classrooms, from the earliest grades through senior high school, will strongly influence *what they learn* and *whether they continue* along the precollege mathematics and science pipeline. The quality of these experiences is determined by the instructional goals and objectives teachers hope to accomplish; the knowledge and processes teachers make available for students to learn; the books, materials, and equipment used to aid student learning; the classroom learning activities teachers arrange; the expectations teachers hold for their students' success; and how teachers interact with their students. These several dimensions of classrooms interact to create opportunities for students to learn, and to determine the extent to which different opportunities are offered to various groups of students.

Students' experiences are likely to differ both between classrooms and between students within the same classroom, and these differences are likely to contribute to unequal participation for minorities and women. We have already noted that minorities are more likely to experience lower-level science and mathematics content as a consequence of their placement in remedial or nonacademic classes. In the following, we consider differences in teacher expectations, teacher behaviors, and classroom activities, and differences in the ways various groups of students respond to the opportunities provided to them.

Teacher Expectations

Differences in the expectations of school adults for whites and middle-class children and those for girls, blacks, Hispanics, and poor children have been well documented (see Persell, 1977, for a review). Some of these differences coincide with school tracking practices, and others concern students on the same track within the same class. Teachers frequently have higher educational expectations for boys than girls (Good, Sikes, and Brophy, 1973; Hilton and Berglun, 1974), and many believe that boys are better at mathematics than girls (Casserly, 1980). One study of elementary teachers found that almost half believed that boys were better than girls at mathematics; *none* of them believed that girls were better (Ernest, 1980). However, these findings should be viewed with caution, since much discussion of higher expectations for girls has occurred during the past decade, and expressed differences in expectations may well have diminished.

That expectations can influence students' attainments is well-known; the phenomenon is documented, for example, in the series of studies following Rosenthal and Jacobson (1968) and the more recent literature on "effective schools" (e.g., Purkey and Smith, 1983; Rowan, Bossert, and Dwyer, 1984). When teachers differentiate expectations on the basis of race, gender, or handicapping conditions, these expectations are likely to erect barriers for minorities, girls, and physically disabled students. Additionally, because of their less-powerful positions in society, lower-class and minority children are more influenced by teacher expectations (Persell, 1977). The same hypothesis may apply to girls and physically handicapped students.

Teacher expectations lead to two central differences in teaching behaviors that will influence achievement: the amount of material taught, and the amount and type of teacher-pupil interactions (Persell, 1977). Teachers have been found to interact differently with students for whom they have high expectations, praising them more often when they are correct, criticizing them less frequently when they are incorrect, and being generally more friendly and encouraging (Brophy and Good, 1974; Kester and Letchworth, 1972). The potential effects of these differences on the science- and mathematics-related attitudes and achievement of underrepresented groups are examined below.

Differentiated Teacher Behaviors and Classroom Activities

Because minority children are disproportionately enrolled in low-level classes in mathematics and science, differences in teacher behavior associated with tracking may be a factor in these students' lower achievement and participation. Teachers of high-track classes spend more time in class on instruction, and they expect their students to spend more time doing homework. They also tend to be more enthusiastic, to present instruction more clearly, and to use ridicule and strong criticism less frequently (Oakes, 1985). These differences, along with the differences in the quality and level of science experiences available in high- and low-track classrooms (Kahle and Lakes, 1983), undoubtedly enhance the learning opportunities of students in more advanced classes and diminish those of students attending predominantly minority schools (Kahle, Matyas, and Cho, 1985). Research is needed to trace the effects of these differences on student outcomes.

Considerably more research has been done on gender-related differences. NAEP data show that boys tend to have more experiences with science equipment and with different kinds of science instruments in elementary school science classrooms than girls, even though girls say they would like to use such equipment (Kahle and Lakes, 1983). Teachers have been found to interact with boys more frequently than with girls during elementary school mathematics instruction and to provide greater encouragement for boys in both science and mathematics (Becker, 1981; Brophy and Good, 1974; Leinhardt, Seewald, and Engle, 1979; Sadker and Sadker, 1986). These differences have been particularly noticeable among groups of high-ability students (Eccles, MacIver, and Lange, 1986; Parsons, Kaczala, and Meece, 1982). Even when the number of interactions does not differ for boys and girls, the *type* of interactions may differ in important ways. For example, Eccles found that in grades 5 through 9, girls for whom teachers had high expectations were subjected to more public criticism, while their male counterparts received more public affirmation.

Some middle-grade teachers spent more time interacting with students for whom they had low expectations than they did with those for whom they had high expectations, but here, too, gender difference were found. Teachers were more critical of boys of whom they expected less and gave more praise to girls (Eccles, MacIver, and Lange, 1986). Finally, teachers at this level were found to gravitate toward groups of boys in sex-segregated classrooms (Sadker and Sadker, 1986).

At the high school level, mathematics teachers have been observed to initiate more interactions with boys and to provide more specific feedback to them (Stallings, 1985).

The actual effects of these gender-related differences are unclear. Despite the apparent effects of teacher expectations, research has not yet firmly established that differences in teacher behaviors actually influence students' attitudes, achievement, or future enrollment in mathematics (Stage et al., 1985; Stallings, 1985). There is some evidence, however, that teacher behavior affects attitudes toward and future enrollments in science. For example, in a study of biology classes taught by teachers who had previously taught chemistry to large numbers of girls who went on in chemistry and chose science-oriented majors in college, both boys and girls had very positive feelings about and experiences with biology materials. Further, girls in these classes indicated that they felt more confident and successful on NAEP items than had 17-year-old girls generally in the 1983 NAEP sample. Experience with these teachers did not overcome all gender-related attitude differences, however. Boys still reported greater interest in science-related careers than girls (Kahle, Matyas, and Cho, 1985). Unfortunately, other than the fact that the girls in these classes reported that they had participated in biology-related classroom experiences as much as boys, we know little about what these teachers did to encourage girls.

Student Responses to Instruction

A third line of work has explored the possibility that differential participation rates may be influenced by differences in the way groups of students *respond* to teaching behaviors and classroom activities. If groups respond differently, and if the most commonly used instructional methods are those that elicit more positive responses from whites and boys, then unequal participation and performance might be linked to the widespread use of methods that favor white males.

Science and mathematics teaching at all levels is dominated by textbooks, teacher lectures, workbook exercises, and writing answers to questions (Goodlad, 1984). These strategies generally focus on presenting knowledge and skills in isolation, rather than in the context of real-life problem-solving. For example, although textbooks may present the steps of the "scientific method" clearly, they usually fail to provide students with opportunities to actually apply these principles of scientific inquiry. Johnston and Aldridge (1984) suggest that this abstract character of instruction may be a fundamental problem in science and mathematics education. That is, high school science and mathematics are taught as an introduction to courses the students will again encounter in college and are largely devoid of practical applications, technology, or the relevance of science to society and its problems (Johnston and Aldridge, 1984). Instruction focused on pure science may be so abstract that students who do not have a high level of reasoning skill or interest find the classes dull and very difficult. Consequently, many students may conclude incorrectly that they are unable to succeed in or learn science.

It has been suggested that minorities and women may have a greater interest in people than in things, and that these groups may respond more positively to ideas in context than in isolation. These groups thus may respond negatively to abstract mathematics and science instruction. There is also some direct evidence that boys benefit from conventional teaching strategies (e.g., whole class instruction and competitive reward structures), while girls and minorities benefit from strategies using cooperative and "hands-on" activities. Girls in competitive classrooms with frequent public criticism have been found to have less positive attitudes toward mathematics than boys, while few or no gender differences have been found in classrooms where few social comparisons were made (Eccles, MacIver, and Lange, 1986). Competitive classroom activities appear to contribute to boys' mathematics achievement but are detrimental to girls' (Peterson and Fennema, 1985). In contrast, cooperative activities contribute to both boys' and girls' acquisition of basic mathematics topics and skills, and to their achievement on high-level mathematics tasks.

Although no sex-related achievement differences in elementary school have been documented, the differential effects of classroom activities may have an effect on girls' attitudes and decisions about mathematics, and these effects may be increased by competitive teaching practices. The implication is that conventional teaching strategies lead to early gender differences in attitudes, which then lead to differences in participation.

There is other evidence that nontraditional instruction can also be more effective for minority children. Black and Hispanic children tend to be more successful in classrooms with cooperative, small learning groups (Au and Jordan, 1981; Cohen and DeAvila, 1983; Slavin and Oickle, 1981; Slavin, 1985) and experience-based instruction (Cohen and DeAvila, 1983). Recent analyses of the effectiveness of activity-based science curricula (e.g., those developed by the Elementary Science Study, Science—A Process Approach, and The Science Curriculum Improvement Study) conclude that while all students benefit from such curricula, disadvantaged students make exceptional gains in understanding of science processes, knowledge of science content, and logical development (Bredderman, 1983). The theories that black and Hispanic children favor learning environments that involve other people and learning tasks that focus on whole concepts or real situations rather than fragmented skills or abstractions (Gilbert and Gay, 1985; Ramirez and Casteneda, 1974) may help to explain why these nontypical classroom approaches are more effective for them.

Perhaps an even more significant factor in girls' and minorities' classroom opportunities is that science instruction is often neglected in elementary schools. On the average, children in grades K–3 spend only about 1-1/2 hours a week learning science, and those in grades 4–6 spend less than 3 hours a week (Goodlad, 1984; Weiss, 1987).

Moreover, elementary school teachers often feel uncomfortable with science. Finally, since science is not usually included on tests that measure children's basic skills, it tends to receive considerably less attention than subjects that are tested. This situation may be particularly detrimental to girls and minorities, since they have far fewer opportunities to participate in science-related activities outside of school (Kahle and Lakes, 1983).

CONCLUSIONS: THE ROLE OF SCHOOLING EXPERIENCES

Trends in adult attainment in college study and occupational choice reflect disturbing trends in elementary and secondary schooling experiences. Race and gender discrepancies in opportunities to learn mathematics and science occur early and appear to increase over time. They become most evident in secondary school, when curriculum tracking and course selection are available to students; women and non-Asian minorities have less access to advice and encouragement in mathematics and science, and they enroll in fewer courses and lower-level courses than white males and Asians (NCES, 1985c). However, differences in secondary school coursetaking patterns are preceded by more subtle differences in students' experiences in elementary classrooms.

Unfortunately, little of the research described above traces the effects of group differences in important classroom dimensions on students' outcomes. Differences in access to school resources, guidance and counseling, science and mathematics knowledge, and classroom experiences do, however, represent critical and policy-relevant interactions that may play a critical role in achievement and decisions to pursue science.

VI. POSSIBLE CAUSES AND CONSEQUENCES: SOCIETAL INFLUENCES

Since most black and Hispanic children are poor, low economic status is a major consideration in understanding minority students' opportunities, achievement, and choices. Additionally, *de facto* discrimination may continue to influence minority students' access to high-quality schooling and jobs and may erect barriers to students' aspirations and attainments. Growing numbers of scholars and women's advocacy groups likewise argue that gender-related differences in societal expectations and childhood socialization create important obstacles to women's confidence, ambitions, and career attainments. Workforce discrimination may work against women's choosing to enter scientific careers. This section briefly overviews the relationship of these social and economic factors to students' schooling opportunities, achievement levels, and choices regarding science and mathematics.

SOCIOECONOMIC FACTORS

Family Status

A connection has been clearly demonstrated between students' SES and their academic performance on a wide range of measures (e.g., grades, standardized achievement and aptitude tests). Home and community background factors have been found to account for 24 percent of the variance in the mathematics achievement of individual 17-year-olds (Welch, Anderson, and Harris, 1982). Similarly, students' SES (defined by education levels of parents, father's occupation, family income, and household possessions) has been shown to account for a substantial amount of the difference in mathematics achievement (Ekstrom, Goertz, and Rock, 1988) and SAT scores of college-bound students (College Entrance Examination Board, 1985). Analyses also suggest that attitudes and SES are related, with children of better-educated parents exhibiting more positive attitudes toward mathematics (Tsai and Walberg, 1983). Minorities' and women's high school performance and postsecondary plans have also been linked with their families' SES (Chipman and Thomas, 1984; Dunteman, Wisenbaker, and Taylor, 1979).

Socioeconomic status is particularly important in understanding racial and ethnic differences in achievement and participation. In

1982, almost half of all black children lived in families with incomes below the poverty line, and black family incomes have shown steady declines relative to whites over the last decade and a half (U.S. Census Bureau, 1982); at the same time, black unemployment rates have been rising (Bureau of Labor Statistics, 1983). Even though employment opportunities for minorities have improved over the past three decades, their jobs are most likely to be found in the lowest-paying and lowest-status positions within their occupations (Wescott, 1982). Hispanic children have socioeconomic disadvantages similar to those of blacks.

Some evidence that SES may be a critical factor in race-related achievement differences can be drawn from data about Asians. Asian-American students are usually considered an anomaly among racial and ethnic minorities. They have the highest rate of participation and achievement in quantitative fields of any of the racial and ethnic subgroups of American students and are significantly overrepresented in scientific careers (Berryman, 1983; NCES, 1985a). However, their high levels of achievement and participation are paralleled by distinct advantages in their home backgrounds: Asian-American students in the HSB sample had the best-educated parents (both fathers and mothers) of any group, participated most in out-of-school educational activities (music lessons, travel, museum experiences), and were most likely to own microcomputers. Only whites equaled Asians in the educational resources belonging to their families—books, newspapers, calculators, etc. Other minority groups lagged far behind on these measures.

Parent Education. Socioeconomic measures may be important primarily because they signal parent education levels, and parent education is the most important predictor of women's and minorities' success and participation in mathematics and science (Berryman, 1983; Malcom, George, and Matyas, 1985). Berryman found that being a second-generation college student equalized the likelihood of choosing quantitative majors across groups of non-Asian minority and white college students, and the same effect was obtained for minority students whose parents had *any* college experience (Berryman, 1983).

Parent education has also been found to be important to women's achievement and participation in science. Women from more privileged backgrounds are more likely to choose scientific majors (Thomas, 1984; Ware, Steckler, and Leserman, 1985), and female science majors (more than males) tend to have mothers employed in relatively high-prestige occupations (Ware and Lee, 1985). A study of engineering majors at the University of Wisconsin found that among otherwise quite similar students, the females' fathers were more highly educated (2 to 4 years of college) than the males' fathers (high school)

(Greenfield, Holloway, and Remus, 1982). Further, mothers' and fathers' education levels are related to women's persistence in scientific majors (Ware, Steckler, and Leserman, 1985).

SES and Achievement. The relationship between achievement and SES may not be as clear-cut as many analyses suggest. White's (1982) careful meta-analytic review of 200 studies reveals important insights about the relationship between SES and achievement: For example, while the relationship is positive and strong (averaging 0.70) when *aggregate* units of analysis are used (e.g., school or district), it is considerably weaker (averaging 0.20) when *individual students* are the unit. Additionally, different SES measures yield considerably different results. The relationships appear to be weakest in studies using traditional measures (e.g., education, income and/or occupation of head of household, and education) and strongest in those using more behavioral family characteristics (e.g., home atmosphere).

Much other work linking SES and achievement, however, points to the need for further investigation and intervention in two areas. First, White's finding of a weak relationship between SES and achievement when individual students are the unit of analysis indicates that there is a great deal of variance in individual achievement within SES groups, and that not all poor children are low achievers. This finding, together with the rather strong relationship found between SES and achievement at the aggregate level, suggests that researchers attempting to explain the relationships found at the school and district level must also examine how school and district characteristics may affect this relationship. Obviously, the schooling factors described in the previous section are good candidates for such work, since these characteristics are more likely to be alterable by schooling policies and practices than are characteristics of individual children's families.

Second, White finds that the SES variables measuring home atmosphere are more strongly related to student achievement than are status variables such as occupation, income, and education. While such home-environment characteristics as parent-child interactions are not likely to be easily altered by education policy and school programs, they appear to be more tractable than income or parent education themselves, and more easily remediated than other effects of poverty, such as inadequate child health and nutrition. Therefore, White's findings provide cause for optimism among those seeking strategies to improve outcomes for poor children.

Parent Involvement and Expectations

Parental involvement can be an important influence on student achievement and participation both at the elementary (Epstein and Becker, 1982) and secondary school levels (Fehrmann, Keith, and Reimers, 1987). Moreover, women science majors more often than their male counterparts have parents who were involved in their high school academic activities (Ware and Lee, 1985). Parental education also affects minorities' choice of quantitative majors through its effects on their high school performance and postsecondary education plans (Berryman, 1983). Parents who have been to college are more likely to expect that their children will also attend, and they tend to put them on the road to college early. These parents are also more likely to understand and encourage the kinds of precollege training necessary for a successful college career. Moreover, many minority and low-SES children whose parents have been to college have already had the "white collar barrier" broken and will have been exposed to a greater variety of majors and adult careers (Berryman, 1983).

Parent education has been shown to have a more positive relationship with persistence in science majors for women than for men (Ware, Steckler, and Leserman, 1985). Highly educated parents expect their children to go to college, and they are more likely to be able to afford educational advantages throughout the children's schooling careers. Perhaps more important, these parents may convey to their daughters less conventional ideas about appropriate behavior for women, and they may be more willing to encourage their daughters in nontraditional pursuits (Ware, Steckler, and Leserman, 1985).

In one study of differences in parents' expectations and the potential significance of their views on students' perceptions of their own interests and abilities, white and Asian females reported far less than other students that their parents thought that mathematics was important to get a good job. (Much higher percentages of black females reported that their parents voiced such opinions.) Although all race and gender groups reported that their parents wanted them to do well in mathematics, far greater proportions of white and Asian males reported that their parents wanted them to take advanced mathematics courses (Matthews, 1980). Three more recent studies found that even when girls' performance equals or exceeds that of boys, most parents believe that girls find mathematics more difficult and think that higher mathematics courses are more important for boys than for girls. Despite their apparently objective inaccuracies, these parent beliefs are related to students' perceptions of their own mathematics ability, future expectations, and coursetaking plans (Yee, Jacobs, and Goldsmith, 1986).

DISCRIMINATION

Many of the achievement and participation differences between minorities and whites disappear when family income and parent education are controlled for. Nevertheless, SES does not *fully* explain the poorer performance of minorities. Differences in science achievement between minority and white and between male and female senior high school students persist even when SES, school experiences, and prior achievement are controlled (Armstrong, 1985; Walberg, Fraser, and Welch, 1986; Chipman and Thomas, 1984; Fennema and Carpenter, 1981; Maccoby and Jacklin, 1974; Stage et al., 1985).

Some of these differences may result from real and perceived race and sex discrimination. For minorities, discrimination in access to education may contribute to lower aspirations and efforts. Important recent evidence indicates that as minorities have gained greater access to education, their overall economic and social position has improved substantially (Smith and Welch, 1986). *De facto* discrimination in educational access may continue to constrain minority achievement and participation.

For both minorities and women, past and continuing workforce discrimination may also be a factor. Historically, even equally well-educated women and minorities—including high-achieving Asians—have been paid less than white males. (United States Commission on Civil Rights, 1978). Recent data on race- and gender-linked differences in employment, utilization, and salaries among scientists suggest that real and/or perceived discrimination may exist within the scientific workforce (Bloch, in NSF, 1988).

While little direct evidence is available, theoretical work suggests that the social and economic consequences of discrimination influence parent aspirations, students' attitudes, and self-perceptions. Anticipation of employment discrimination and, for women, the difficulty of combining the demands of science careers with other social and cultural expectations may be significant in shaping these attitudes (Chipman and Thomas, 1984). Perceptions of job opportunities can be an important factor in the college-major choices of black college men (Thomas, 1984). The perceived utility of mathematics and science and the stereotyping of these subjects as the purview of white males flow logically from these social conditions.

CONCLUSIONS: THE INFLUENCE OF SOCIETAL FACTORS

The influence of societal factors on the attainments of women and minorities cannot be overlooked. Undoubtedly, they play a significant role in race and gender differences in achievement and decisions to pursue science. While the relationship of socioeconomic factors to student achievement, opportunities, and choices has been extensively documented, the mechanisms through which social factors actually work have received far less attention. However, recent work provides some insight about how out-of-school factors may influence students' attitudes and behaviors relating to achievement in school.

Considerable psychological research supports the influence of environmental conditions on children's beliefs about their prospects for success and the rewards they can expect, and about the effects of self-perceptions and expectations on school performance. Self-efficacy (closely related to confidence in ability) depends, first, on how responsive the environment is to an individual's attempts to gain rewards, and second, on the perceptions of others about that person's efficaciousness. When individuals are placed in subordinate roles or given labels that imply inferiority or incompetence, their self-efficacy and performance are often negatively affected (Bandura, 1982). Students appear to respond to school in ways that seem reasonable to them, given the messages schools and the larger society send them about their prospects for success. For poor minorities and girls, the messages about science and mathematics can be discouraging.

Most middle-class children and their families—minority and white—expect that school success will bring real-life rewards in the form of good jobs and salaries. This provides considerable motivation for the hard work that school learning requires. Most of these children have parents and friends who were successful at school and who expect them to do as well, and, for many, these expectations are echoed by the adults at school. While these factors don't automatically ensure success for schools serving middle-class children (indeed, many such schools have considerable difficulties), they certainly ease the schools' task.

On the other hand, minority children in central cities have little real-life experience to support such beliefs and expectations. Some know few adults who have achieved at school or who have translated school achievement into economic gain. On the other hand, they may know many "streetwise" teenagers and adults who exchange their informal knowledge and skills for success "on the street" (Valentine, 1979; Weiss, 1985). In many central-city schools, teachers and administrators may not be salient models for success, particularly if they don't live in the communities where they teach, or if they have little contact with children's families. Moreover, these adults may have only modest expectations for the children attending their schools. Some urban minority children have neither churches nor community organizations to support their school efforts or provide contacts with successful, educated adults. These conditions undoubtedly make the task of schools very difficult.

Poor minority children and their parents frequently respond to school opportunities quite differently from people in more privileged communities. These responses may contribute to young children's lower levels of academic achievement; to adolescents' higher rates of truancy, inattention, misbehavior, and dropping out; and to high schoolers' low rates of participation in science and mathematics.

Yale psychiatrist James Comer suggests that the psychological and social distance between schooling and poor minority children's larger environments did not exist for earlier generations of poor children. The families of earlier generations of poor minority children worked and sometimes lived among the middle-class, who provided daily models of a better way of life:

> Employment opportunities generally played a major role in enabling families to feel they were a part of the American mainstream and in motivating them to embrace its attitudes, values, and ways. As a result, children from such families had access to social networks of experience, information, and opportunities that facilitated good education and future opportunities for them (Comer, 1985, p. 246).

Education policy alone can do little to change the current context, shaped as it is by racism, poverty, unemployment, and isolation. At the same time, schooling remains the best opportunity available to poor minority students for interrupting the predictable cycles of poverty, undereducation, unemployment, and social disintegration.

Similar relationships between societal factors and school attainment undoubtedly exist for women and disabled students.

The Nexus of Race, Class, and Schooling

Societal factors do not operate independent of students' experiences in schools. The evidence about schooling differences cited above suggests that schools, too, respond to race, class, and gender in ways that exacerbate the difficulties of girls and minorities in science and mathematics. The interplay and relationships among individual student characteristics, societal influences, and schooling opportunities are undoubtedly the key to understanding and improving the participation of underrepresented groups.

Some analysts have hypothesized that both schooling opportunities and students' responses to schooling are influenced by the norms and expectations of the current social milieu about different groups of students. Schools' definitions of individual differences and decisions about what opportunities should be provided to different students may thus be influenced by social as well as educational factors. Societal factors may influence student outcomes through their direct effects on teacher attitudes, school mathematics curricula, and students' attitudes and achievement-related behavior (e.g., coursetaking), and through their indirect effects on classroom processes and student achievement (Reyes and Stanic, in press). Factors in the larger society may also be linked to student outcomes through their influence on the structure and climate of individual schools (Oakes, 1987).

CAUSES AND CONSEQUENCES: AN OPTIMISTIC FINDING

Despite the wealth of studies describing differences among racial and gender groups, we have developed relatively little understanding of how such differences are produced. Nonetheless, one rather optimistic conclusion appears to be supported by these diverse studies: Both in and out of school, those resources, experiences, and attitudes that encourage and support white boys in mathematics and science also appear to encourage girls, minorities, and poor students. In nearly all studies, such factors as prior achievement, coursetaking, expectations of parents and school adults, academically oriented peers, interest in science and mathematics, perceived future relevance of these subjects for career and life goals, and confidence in ability have been found to be related to achievement and participation for *all* groups of students.

Moreover, analysts who have modeled the way various factors influence achievement find similar processes at work across race and gender categories. Recent studies (Wolfle, 1985; Wolfle and Ethington, 1986) have used structural-equation methods to determine whether the process of attainment is similar across different racial and gender groups. This work is particularly important in view of previous research that suggested that the processes of educational attainment are different for blacks and whites (see, for example, Kerckhoff and Campbell, 1977; Porter, 1974; Portes and Wilson, 1976) and that females may need different educational experiences from males.

Using data from NLS and HSB, Wolfle demonstrated that few differences exist among groups in the factors that lead to achievement or in the relative importance of those factors. Across racial groups, SES influences ability; ability is the best predictor of placement in an academic curriculum, with social background factors having a far more modest direct effect; and placement in an academic track is the most important predictor of postsecondary attainment for both blacks and whites. Moreover, equal changes in either social-background variables or within-school variables lead to the same outcomes for both groups. These analyses suggest strongly that the process of educational attainment is the same for both blacks and whites.

Jones (1985) also found the relationship between senior-year mathematics scores and a composite of predictors, including coursetaking, to be the same for all racial and gender groups. Ware and Lee (1985) found the same model useful for explaining achievement among HSB male and female seniors, even though it was a slightly stronger predictor for males.

This work suggests that race- and gender-related differences may be caused less by *unique* needs of women or minorities than by the fact that these groups typically have less access to the positive factors that work in favor of high achievement and continued participation generally. This is a critical point for understanding the causes of low achievement and underrepresentation and for developing interventions to increase participation.

VII. INTERVENTIONS TO INCREASE PARTICIPATION

Over the past several years, a number of interventions have been developed to increase the participation of girls, minorities, and physically disabled students in scientific careers. Most of these programs are aimed at increasing students' opportunities for science and mathematics experiences, improving their achievement, and influencing their choices. The design of these interventions generally reflects the hypotheses about the causes of racial and gender differences that have guided the research described above. The following typical program goals reflect most of the common assumptions about the causes of race- and gender-related differences:

- Promoting students' awareness of and interest in science careers.
- Developing positive attitudes toward science and mathematics and students' confidence in these subjects.
- Developing scientific competencies, e.g., problem solving and logical thinking.
- Increasing student participation in high school science and mathematics courses that are prerequisites for quantitative majors in college.

To date, however, most intervention programs have added little information about the causes of underparticipation and have provided little specific guidance for the development of effective interventions. Few programs have been designed in ways that permit controlled studies of their processes and outcomes. While some programs have included collection and reporting of evaluation data on their effects, few have been subject to systematic inquiry. Even less effort has been made to analyze the effectiveness of various program features or to assess the conditions under which particular interventions are effective. Consequently, we know little about which types of programs are most effective for different purposes, or with different groups.

Recently, however, some researchers have attempted to catalog existing interventions and gather basic information about them. These efforts, sponsored by the National Science Foundation and the U.S. Department of Education, together with evaluation reports on a few individual projects, provide the best information currently available about the interventions that are being attempted.

In 1983, the American Association for the Advancement of Science (AAAS) identified 312 precollege intervention projects (Malcom, 1985). Seventy percent of the programs had a mathematics focus, although most were interdisciplinary. Most were housed at universities, museums, and research centers; and most were at the high school rather than the elementary or middle school level. Minority and disabled women were underrepresented in these programs.

A survey of 163 intervention programs for 4th through 8th graders (Clewell, Thorpe, and Anderson, 1987) found that 13 percent of the programs were aimed solely at girls, and 33 percent primarily at minorities; the remaining 54 percent were geared toward a combination of minority and female participation. Twenty-nine percent of the programs emphasized mathematics exclusively, 17 percent emphasized science, and 4 percent focused on computer science; 64 percent of the programs included all three areas. Those programs focused on minority participation tended to emphasize achievement, while those aimed at females stressed attitudes.

A group of school and college programs specifically serving Mexican-Americans in the Southwest were found to vary in terms of target student population (ages, ability levels, etc.), staffing patterns, and activities (Rendon, 1985). Most of these programs are collaborative efforts. However, the type of partners varies across programs—e.g., some involve school districts, colleges, and industry; others, consortia of colleges; and others, educational institutions and Hispanic organizations. Most have been funded by a combination of public and private monies.

These reviews suggest that intervention programs vary considerably in substance, format, duration, locales, and target groups. However, many have common goals and activities, and most draw on correlational research linking particular types of experiences to participation and achievement in science and mathematics. Most of them emphasize career relevance and applications of knowledge, and they typically include the following types of activities: (1) opportunities to practice the scientific method and conduct research projects; (2) participation in hands-on science experiences; (3) using computers and learning programming; (4) opportunities to learn about scientific careers; (5) contact with role models and interactions with scientists and mathematicians; and (6) counseling about high school course selection. Many interventions for women and minorities have been very selective, targeting their programs at the highest-achieving students or those seen with high potential. While we have not attempted a comprehensive review of programs, the following examples are illustrative of program types. They do not necessarily represent the best programs of their type.[1]

INTERVENTIONS

Interventions Aimed at Girls

Classroom Interventions. A number of interventions have attempted to incorporate "girl-friendly" teaching strategies into regular classrooms. The strategies are based primarily on research that has shown cognitive and affective advantages for girls in informal learning environments where students have equal access to materials and equipment and use cooperative or peer learning. In some cases, single-sex courses have been designed to eliminate the more competitive, male-dominated classroom environment. One apparently successful attempt at teaching college-level mathematics to girls was developed by the University of Missouri-Kansas City as an alternative to the regular introductory mathematics course. In the all-girl class, instruction was more informal and less competitive than in the regular section, and the subject matter was discussed in its social context along with other social issues. Role models were provided in the form of female mathematics graduate students and professors. Although the students in this class had been initially identified as weak in mathematics, they elected to continue their mathematics education at a higher rate than girls in the regular mathematics section. They also reported a much more enjoyable experience in mathematics than did girls in the control class (MacDonald, 1980; Stage et al., 1985).

To counter the hypothesized effects of negative attitudes on girls' achievement and choices, other classroom-based programs have focused primarily on helping precollege-age girls be more positive about mathematics and making them more aware of its usefulness in future careers and college work. Such interventions typically incorporate new curriculum units into regular classrooms (e.g., Fennema's videotapes on "Multiplying Options and Subtracting Biases") or enrichment activities that increase awareness and mathematics skills. One such program, "Solving Problems of Access to Careers in Engineering and Science (SPACES)," offered through Lawrence Hall for Science at Berkeley, is a set of classroom enrichment activities for girls in grades 3 through 10 intended to improve girls' mathematics and problem-solving skills and

[1]For more comprehensive descriptions of interventions, see Beane (1985); Clewell, Thorpe, and Anderson (1987); Lockheed (1985); Malcom (1985); and Rendon (1985).

also provide career awareness in mathematics and science. An evaluation in 100 classrooms found that the program resulted in improvements in career interest, career knowledge, identification of science tools, word problem-solving skills, and spatial visualization. Other programs, such as the COMETS program at the University of Kansas, have applied the same format to more scientific domains (see Stage et al., 1985, for a review).

Research exploring links between confidence and persistence in mathematics has led to the development of classroom programs that address the special fears and problems of women. Some include counseling sessions on math anxiety; others address specific learning problems. A course at San Francisco State University on learning mathematics without fear attempts to help students conceptualize mathematics instead of memorizing a lot of rules (Stage et al., 1985). Other programs address confidence problems that result from a lack of prior experience with scientific materials, computers, and mechanical equipment. In Purdue's school of engineering, special "hands-on" lab courses were given to freshmen engineering majors, with a special emphasis on women and minorities. Of the women who attended these special courses, along with lectures presented by role models, reading and discussion sections, and career counseling, 78 percent were still in the engineering program after two years, as compared with only 62 percent of the control women (LeBold, 1978).

Extracurricular Interventions. A number of extracurricular programs have been designed to make up for possible gender bias in regular school programs and to provide additional compensation for negative factors in girls' out-of-school environments. Most of these programs attempt to influence both attitudes and cognitive abilities. Many programs include guest lectures, which serve the dual function of exposing students to role models and conveying information. For example, the Visiting Women Scientist Program sends women scientists to secondary schools, where they conduct lectures and informal discussions in small groups. Guidance counselors at participating schools have reported higher proportions of girls asking for information about science-related careers than at control schools (Stage et al., 1986). Other programs involve workshops (e.g., NSF Science Career Workshops) or conferences (e.g., Expanding Your Horizons in Science and Mathematics Conferences) designed to increase women's interest in science and provide information about future careers involving mathematics and science (Stage, 1985).

Some extracurricular programs have also attempted to implement girl-friendly approaches to mathematics instruction. At The Johns Hopkins University, an experimental group of mathematically gifted junior high school girls were taught algebra during a summer session by a group of women mathematicians in a relaxed, noncompetitive atmosphere. Two years later, a higher proportion of these girls had persisted in mathematics courses than had girls in a control group (Brody and Fox, 1980).

Interventions Aimed at Minorities

Most intervention programs for minority students reflect the hypotheses that additional science and mathematics experiences, altered instruction, career information, and contact with role models will improve achievement and increase later participation. Consistent with what is known about minority underparticipation, these programs focus on boosting academic achievement.

Classroom Interventions. A number of classroom interventions for minorities have been based on the hypothesis that these groups will achieve better and develop a greater interest in mathematics and science in informal, less-competitive classroom environments. Many programs train teachers to increase the amount of hands-on science activity and incorporate peer teaching into classroom instruction. In San Jose, California, the implementation of a conceptually rich, experience-based, cooperative bilingual science curriculum, *Finding Out/Descubrimiento* (Cohen and DeAvila, 1983), has not only boosted children's science achievement, but has had positive effects on standardized reading and mathematics test scores as well.

Project SEED (Special Elementary Education for the Disadvantaged), operating in a number of schools throughout the country, brings scientists and mathematicians into elementary schools to teach mathematics on a daily basis to disadvantaged students. SEED supplements the regular curriculum with instruction in abstract mathematics concepts and avoids remediation, in the belief that this approach will develop childrens' confidence and interest in mathematics. Evaluation data suggest that students in the program have made achievement gains of two months for each month in the program (Lockheed et al., 1985).

Extracurricular Interventions. Extracurricular programs developed to motivate minorities' career interest and performance in science and mathematical fields are aimed primarily at highly able or promising students who are identified early—often in the junior high school years. Typically these programs consist of rigorous, out-of-school academic programs. Some include an afternoon program, i.e., the student goes to his or her regular school in the morning and attends a special school in the afternoon; others are summer or weekend programs. Some programs are aimed at preparing students for quantitative majors in college, while others attempt to prepare students for work in technological fields immediately upon high school graduation.

The MESA program, headquartered at the University of California's Lawrence Hall of Science, is perhaps the most wide-ranging extracurricular intervention program for minority students. Aimed at junior high, senior high, and college students, MESA provides study groups, activities, field trips, summer enrichment programs and employment, and scholarships. The program also emphasizes parental involvement. MESA currently includes over 30 university centers which support activities at nearly 200 schools and several colleges. Similar programs are operated by the Minnesota and Philadelphia public schools and by other universities. In a number of the university-based programs, students are required to take advanced mathematics courses and to maintain a specified grade point average in order to participate. An extensive evaluation of MESA programs found that participating students performed academically at levels above their minority peers nationally, and at levels similar to those of college-bound students, regardless of ethnicity (Atwood, Doherty, Kenderski, and Baker, 1982).

The university-based SECME (Southeastern Consortium for Minorities in Engineering) program identifies promising black children in late elementary school and provides them with encouragement to continue in mathematics. Although selection bias is not controlled, program evaluation data report that 80 percent of SECME students go on to college (compared with 50 percent of black high school students in general), and that 41 percent of them choose to major in mathematics, science, or engineering. Moreover, SECME students outperform the national average for blacks by 140 points on the SAT (Campbell, 1986).

In some geographic regions (e.g., Texas), local companies have shown considerable interest in increasing minority, especially Hispanic, participation in mathematics, science, and engineering. These companies fund field trips, contests, science fairs, small scholarships, etc., for promising minority students in small towns. There has been little systematic evaluation of these programs, which include TAME (Texas Alliance for Minorities in Engineering) and STEMS (South Texas Engineering, Mathematics, and Science Program), but for the most part, they provide outside-of-school activities for high-achieving students (see Rendon, 1985, for a review).

At the college level, programs have been designed to help minority students make career and program decisions and to persist in their chosen fields (Rendon, 1985). Examples are the Professional

Development Program at Berkeley which offers enrichment courses in math, English, and science to high achieving minorities, and the Minority Biomedical Research Support Program and the Biomedical Research Program for Ethnic Minority Students at the University of New Mexico which offers close student-faculty interactions through apprenticeships and independent research programs.

Interventions for Teachers and Parents of Girls and Minorities

A number of efforts have been made at both the preservice and inservice levels to increase teacher awareness of the importance of math education, to promote nondiscriminatory teaching practices, and to make teachers themselves, especially at the elementary level, comfortable with mathematics. The theory behind these programs is that if teachers are anxious about math, or do not have a good idea of how to present mathematics topics, they may convey mixed messages to their women and minority students. EQUALS, begun at Berkeley and now replicated in other sites, provides materials and teacher training on equitable teaching and counseling practices related to mathematics and computers. Improving Teacher's Ability to Visualize Mathematics and TEAM are two projects designed to help teachers feel more comfortable with teaching mathematics.

A few programs have focused on parents. One such program, Family Math, also from Berkeley, aims at helping parents of low-achieving minority students engage in problem-solving activities with their children. Parents are taught hands-on mathematics tasks to do at home to supplement the school curricula. The program also provides role models and career information.

Interventions for Physically Handicapped Students

Far fewer interventions have been developed for physically handicapped students, and many of the existing programs have emerged in response to Public Law 94–142, which mandated that handicapped children be taught in the "least restrictive environment." These programs have focused primarily on improving the access of physically handicapped students to science instruction in mainstreamed classrooms and on improving science teachers' skills in working with students with disabilities.

In the late 1970s and early 1980s, NSF funded a number of efforts to provide positive science experiences for disabled students and their teachers. In 1980, the American Chemical Society, with NSF support, sponsored a workshop that led to the development of guidelines for teaching chemistry to physically handicapped students and for making teachers more sensitive to the special needs of such students. Additionally, some teacher training courses were developed. One of these, the AAAS-developed course, "The Physically Handicapped Student in the Science Classroom and Laboratory," was intended to help college and university teachers deal effectively with handicapped students. Finally, some projects focused on handicapped students themselves, providing both guidance and actual science experiences. One summer program which provided disabled college students with research experiences at Argonne National Laboratory reported very positive evaluations from staff and students (Rauckhorst, 1980).

The Lawrence Hall of Science program, "Science Activities for the Visually Impaired/Science Enrichment for Learners with Physical Handicaps," provides materials and instructional strategies for elementary school teachers. The program emphasizes adapting science activities in mainstream classrooms to accommodate students with disabilities. The adaptations have been shown to permit disabled students to engage in science activities and have also improved relationships between students with disabilities and their able-bodied peers (Thier, 1983). The success of the project is consistent with evidence on the successful adaptation of laboratory equipment for visually impaired students over the past 30 years (Cetera, 1983).

Finally, a series of support efforts has been undertaken by the AAAS Project on Science, Technology, and Disability which include the publication of a newsletter and resource lists and the placement of disabled students in out-of-school programs in science (Stern, 1987).

DO INTERVENTIONS WORK?

Few intervention programs have been rigorously evaluated or researched. Many programs have documented positive effects on students' attitudes and participation in mathematics and science, but it is difficult to draw firm conclusions from these data. An exclusive focus on high-achieving students in many of the extracurricular programs makes evaluation findings difficult to interpret. Additionally, it is nearly impossible to use disparate evaluation data to look for common features that contribute to the success of different programs. However, a number of analysts have identified program characteristics they believe may be most effective in promoting greater participation in science careers.

Malcom (1985) concludes that critical program characteristics for both women and minorities include (1) academic enrichment focus; (2) teacher competence; (3) emphasis on applications of science and mathematics; (4) integrative teaching, hands-on activities, and computers; (5) multiyear involvement; (6) a strong director and low staff turnover; (7) recruitment of participants; (8) cooperation between university, school, and/or industry; (9) a stable long-term funding base; (10) opportunities for in-school and out-of-school learning experiences; (11) parent and community involvement; (12) role models; (13) peer support systems; and (14) the institutionalization of program elements into regular schooling (Malcom, 1985).

Similarly, Stage (1986) has found that programs which are successful in encouraging girls' science participation contain a strong academic program, an integrated approach to teaching science and mathematics, and a heavy emphasis on applications and career relevance. Stage concludes that the following types of programs should be supported by research: (1) single-sex classes for girls and women; (2) classes that specifically address girls' anxieties about quantitative subjects; (3) curricula for regular classes that address girls' special needs; (4) teacher education programs that include cooperative learning strategies; (5) school-district-level monitoring and planning for girls' achievement, course enrollment, and extracurricular activities.

A review of interventions for students in grades 4 through 8 suggests that program characteristics likely to be effective in developing positive attitudes include encouragement from significant others, career information, contacts with professional scientists as role models, and rewards for achievement (Clewell, Thorpe, and Anderson, 1987). Program characteristics related to increased participation include academic counseling and encouragement to participate in mathematics and science clubs and community programs. Characteristics linked with increasing academic skills and performance include hands-on experience, participation in competitions and science fairs, cooperative and small-group learning, and tutoring. Finally, characteristics linked with career choice include counseling and monitoring of students' academic programs throughout high school.

Finally, Rendon concludes that successful programs for Hispanics are those housed at sponsoring schools or colleges that have the participation of minorities as an overriding institutional priority; moreover, the activities of these programs reflect important goals of the institutions' science and mathematics departments, and full-fledged professionals are charged with developing and implementing the programs. These characteristics place the intervention programs in a central role in the institutions. The most successful collaborations linked schools with colleges and also involved corporate sponsors as contributors and advisers. The most effective programs provide close, daily interaction with students both in and out of the classroom and offer students both academic and personal support. Finally, the most promising efforts appear to be those that intervene early, capturing minority students before they fall behind academically in elementary and junior high school.

While none of these conclusions is based on rigorous research, all are fairly consistent with the literature on participation, i.e., they endorse efforts to compensate for race- and gender-related differences thought to be linked with participation. The recommendations of the reviewers cited above also concur with more general recommendations for improving the overall quality of science and mathematics education, and they mesh with our increasing understanding of the qualities of effective schools. However, far too little is known about specific program characteristics and outcomes to make precise conclusions or recommendations for the development of interventions that will be effective with different groups for different purposes. We need to know a great deal more about which strategies promote higher achievement among low-achieving minority students; which positively affect girls' and/or high-achieving minority students' decisions to continue in mathematics and science; and which provide essential opportunities not available to various groups at school or at home. We need to know the ages at which various strategies have the greatest effect; the groupings of students (e.g., high achievers, low achievers, single sex, a mix of minorities and girls) for which programs work best; and the settings (in or out of the regular classroom) in which various strategies are most effective.

VIII. ISSUES FOR FURTHER RESEARCH

The participation of women, minorities, and the handicapped in science is a complex, multidimensional issue. Consequently, it is not surprising that the research on the subject has been uneven, both in its coverage and in the understanding it provides. A number of analyses have described how women differ in their mathematics achievement, attitudes, and experiences (both in and out of school), and have examined these differences at a number of critical points in women's schooling and their adult careers. Other areas have received considerably less attention. For example, less is known about the science participation and achievement of women, and even less is known about racial minorities' mathematics and science participation. Less is known about Hispanics and other minorities than about blacks, and almost nothing is known about the achievement and participation of physically disabled students. Finally, little investigation has been conducted on the impact of various intervention strategies or has explored the conditions under which particular types of strategies are likely to be effective.

The existing work does, however, provide many clues about factors that are strongly associated with various groups' progress, or lack of progress, through the educational pipeline. We have learned that opportunities to learn mathematics and science, achievement in these subjects, and choices about whether to pursue study in scientific fields are centrally important to whether students participate in scientific endeavors as adults. These factors also seem to be central to the level of scientific literacy students attain. Yet we know little about what causes group differences in opportunities, achievement, and choices, or how differences along one of these dimensions relate to the others (e.g., how the presence or absence of various learning opportunities may influence choices). These gaps result partly from the fact that little experimental research on race and gender differences has been performed using longitudinal data. Where longitudinal data have been available, analysts have been able to derive more useful conclusions about the determinants of participation (e.g., the link between course-taking and achievement).

Part of the difficulty lies in the complexity of the problem itself. While we have learned a great deal about associations among a wide range of variables that seem to be linked with participation for particular groups, the issue is unlikely to be resolved by the manipulation of empirical data alone. Work is needed on the causes of racial, gender, and handicap-related differences in participation. Little solid grounding currently exists for interpreting the meaning of relationships among variables, for suggesting underlying processes and conditions that may create group differences, or for speculating about processes and conditions that might be altered to effectively increase participation. Analysts have had considerable difficulty interpreting findings and deriving trustworthy policy implications from them.

Future studies should include basic research on how individual factors such as cognitive style and self-efficacy may be linked to race and ethnicity, gender, and handicaps. Other work might profitably focus on societal issues such as family and community socialization.

Most essential for policymakers, however, is research on how *alterable* features of schooling may contribute to group differences and on changes in schooling that may increase the achievement and participation of underrepresented groups. It is important to push beyond the limits of prior work. Research designs should be developed that address the causes and consequences of race, gender, and handicap differences, and theoretical work that places the specifics of these differences into a larger framework should be strongly encouraged. Some promising directions for such policy-relevant research are presented below.

TRENDS IN PARTICIPATION OF WOMEN AND MINORITIES

Highest priority should be given to continued and expanded efforts to monitor overall trends in the status of women and minorities in science and mathematics and to translate these data into "indicators" that are accessible to policymakers and educators. Currently, data generated by the Census, NSF surveys, the College Board, and the Department of Education's Center for Statistics enable analysts to chart the achievement, senior high coursetaking, college attendance, and degree attainments of blacks, Hispanics, and women. These national databases have been central to our current understanding of participation. Proposed expansions in NAEP and the upcoming Department of Education's National Educational Longitudinal Study (NELS) should permit even more comprehensive monitoring. For example, NELS will provide much needed longitudinal data beginning with students' junior high school experiences.

However, sample sizes must be large enough to permit disaggregation of data by the range of racial and ethnic groups, by gender groups within racial and ethnic groups, and by social class differences among these groups. Few datasets currently permit analysis of the experiences of important racial and ethnic subpopulations: Mexican-Americans, Central Americans, Puerto Ricans, Cubans, Chinese, Vietnamese, Japanese, and Filipinos. Recent work has suggested that race, gender, and social class are inseparable and interactive influences on children's educational experiences, achievement, and occupational attainments, and that analyses that treat racial groups, gender groups, or social class groups as homogeneous oversimplify and mislead (Grant and Sleeter, 1986). However, few national databases are adequate to permit analyses of achievement and participation differences by social class subgroups within minority groups.

Except for the NSF survey of scientists, national data now provide little information about the status of physically disabled persons in science and mathematics education and careers, and even the NSF survey is flawed. If charting the participation of this group continues to be an issue of national concern, data collection efforts will need to modify the substance of surveys and sampling strategies to generate data that will permit monitoring participation of the physically handicapped.

RELATIONSHIPS BETWEEN SCHOOL CONDITIONS AND MINORITY PARTICIPATION

New research is needed on the relationships between schooling conditions and minority students' learning opportunities, achievement, and career decisions. Of particular interest would be studies that examine how particular features of schooling interact with students' individual characteristics (e.g., attitudes) and social background (e.g., social class). Such research should extend from children's earliest schooling experiences with science and mathematics through college students' pursuit of or defection from scientific fields.

Since the low achievement levels of most minorities preclude participation in mathematics and science, the most urgent need is to understand the effects of schooling factors on the achievement of these children in the earliest grades. While national databases have provided evidence that the minority-white achievement gap has been steadily decreasing over the past several years, we need to know how further increases might be fostered by changes in schooling.

At the most basic level, the schooling experiences of black and Hispanic minorities must be thoroughly documented. Then, applied research is needed to identify effective schooling strategies for boosting achievement. The following questions should be addressed:

- What types of mathematics and science opportunities are provided to black, Hispanic, and other underrepresented minority students? How qualified are their teachers? How much time is spent on science and mathematics instruction? What teaching strategies are used? What types of facilities and materials are used? What is the curricular emphasis—e.g., basic-skills instruction, experience-based activities, etc.? What grouping strategies are used? What language is used for instruction of bilingual students?
- What are the less tangible characteristics of minority schooling in science and mathematics—e.g., what expectations do teachers have, what kind of encouragement do they provide, what kind of academic guidance and career information is available from counselors?
- Are there school-level differences in opportunities and effects for minority students? For example, are students who attend predominantly minority schools disadvantaged in comparison with those attending predominantly white schools? Does school SES make a difference in the opportunities provided?
- How do different school and classroom resources, curricula, and learning experiences affect students' attitudes toward science and mathematics (particularly confidence in abilities, perceived usefulness of these subjects, and attributions for success and failure) toward science and mathematics? Their achievement? Their further participation in these subject areas?
- What are the effects of various types of supplementary and compensatory school programs on early mathematics and science achievement? For example, what are the relative effects of basic skill instruction, activity-based learning experiences, small-group work, individual tutoring, etc?
- What are the effects of various school and classroom experiences on the decisions of high-achieving minorities to pursue study in quantitative fields?

RELATIONSHIPS BETWEEN SCHOOL CONDITIONS AND WOMEN'S PARTICIPATION

Girls' level of achievement in mathematics and science does not prevent them, as a group, from pursuing advanced study in these fields. While their mathematics achievement dips below that of boys at the senior high school level and is slightly lower in science in earlier grades, achievement differences alone are insufficient to explain the large disparities in participation. We have considerable evidence of gender differences in attitudes toward mathematics and science, with women, for the most part, being more negative about science and about the role it might play in their future lives. However, there is little evidence about the role these attitudes play in later achievement differences or in decisions about future careers. Work is needed that explores how attitudes may work together with other individual and societal factors to contribute to women's lower participation.

Even more important for education policy purposes is a better understanding of how schooling conditions may contribute to these differences or interact with them to produce disparities in achievement and choices. Questions similar to those listed above should be explored, with the focus on the effect of school and classroom experiences on the attitudes, achievement, and persistence of women. Relevant questions would include the following:

- How do girls' school and classroom experiences in science and mathematics—e.g., classroom interactions, instructional strategies, access to science equipment and computers, teacher expectations and encouragement, academic guidance from counselors, career information, etc.—compare with boys'?
- How do different school and classroom experiences affect girls' attitudes toward science and mathematics (particularly confidence in abilities, perceived usefulness of these subjects, and attributions for success and failure)? To their achievement? To their further participation in these subjects?
- What effects do various school and classroom experiences have on the decisions of high-achieving girls to pursue study in quantitative fields?

As with research on minority participation, studies of girls' schooling experience and their effects should span the range of elementary and secondary schooling.

RELATIONSHIPS BETWEEN SCHOOL CONDITIONS AND THE PARTICIPATION OF PHYSICALLY DISABLED PERSONS

Because of the virtual absence of research on the participation of physically disabled people, the most useful new efforts might focus on developing research frameworks. Work will also be needed on the difficulties of measuring handicap status. Initially, we can expect problems in defining disability status, framing measures, and developing data collection procedures. Efforts should be initiated to document and assess how effectively schools have adapted science and mathematics instruction to accommodate physically disabled students. Particular attention should be given to the interaction of school processes with the age of onset of disabilities and students' coping strategies.

EVALUATING THE EFFECTIVENESS OF INTERVENTIONS

It will be necessary to identify and document those special intervention programs developed by schools, universities, museums, businesses, and/or communities in mathematics and science that have effectively increased achievement among low-achieving minorities; increased further participation among high-achieving minorities; increased persistence and scientific choices among girls and women; or increased the access of physically disabled persons.

It is important to look not only at the effects of programs per se, but also at the effects of various program types and particular program features. For example, the following questions should be addressed:

- What activities are characteristic of the most successful programs for increasing learning opportunities? Achievement? Choices? What formats are employed? What staffing patterns? What durations?
- What are the effects of various types of mentor programs toward various ends? What characterizes effective relationships between students and mentors? By what age should mentoring relationships begin?
- What are the effects of providing career information? In what form? At what age?
- What are the effects of role models? How effective are contacts with professional scientists and mathematicians? Contacts with minority and female role models?
- What are the effects of early experience on college campuses? For highly able students? For average or low-achieving students?
- What are the effects of single-sex intervention environments on girls?
- What types of programs are suitable for integration into regular classrooms? Which are most effective as extracurricular, afterschool, or summer activities?
- How might parents be effectively involved in special mathematics and science intervention programs?

- What types of financial assistance or other incentives might be both feasible and effective in encouraging poor minorities' and women's choices of scientific fields and persistence in higher education?

Researchers should also consider the ages at which particular strategies are most effective in achieving various goals, and the differences in effectiveness of particular types of strategies with various racial and ethnic groups, with women, and with disabled students. This line of research could be particularly useful for suggesting ways in which schools can adapt their "regular" programs to achieve more successful outcomes.

INTEGRATED RESEARCH ON RACE, GENDER, AND SOCIAL CLASS

New studies will provide greater insight about race and gender differences and will be considerably more useful in framing policy if they integrate analyses of race, gender, and social class—i.e., if they consider the *combined* influences of students' multiple status characteristics, or if they enable analysts to disentangle such typically confounded effects such as race and social class.

This conclusion is drawn from recent studies of gender differences within racial groups that have found different patterns in these subgroups. For example, although more boys overall enroll in advanced high school mathematics courses than girls, the opposite pattern has been found among black students (Matthews, 1984). Additionally, national data show that even though more black women than men begin college studies in science and mathematics, fewer of them earn advanced degrees (National Science Foundation, 1986). Other work suggests that lower-class minorities may follow different patterns than middle-class minorities (Grant and Sleeter, 1986). Such analyses suggest that students' race, gender, and social class all relate in important ways to different school conditions and must be considered in framing appropriate intervention strategies for various groups. Wherever possible, studies of factors that contribute to participation should consider all of the students' relevant characteristics.

EXPLAINING UNDERPARTICIPATION

Finally, research is needed that moves beyond simply describing patterns of differences among various groups and correlating those differences with participation. It is essential to develop and test new theories about how these differences are produced. Work should be directed toward explaining the contribution of individual, societal, and schooling factors to lower achievement and participation among black and Hispanic students, and to women's lower rates of choosing courses and careers in mathematics and science. Some tentative models have been suggested (Oakes, 1987; Reyes and Stanic, in press; Gardner, 1987; Peterson and Fennema, 1985), but they remain underdeveloped and largely untested. Moreover, they are firmly grounded in currently accepted relationships between race, class, gender, and schooling. In a recent discussion of gender-related research, Marini (in press) recommended that future model building should break out of the immediate situational circumstances that shape participation for any one group. Such work should attempt to develop and test theories that link the production of group differences to more general theories about basic social processes such as stratification and status organization. New theories could reveal relationships between mathematics and science participation and these more fundamental social processes. Such research could provide much more complete explanations of *why* and *how* group differences in participation develop, and a far more solid basis for interventions aimed at remedying discrepancies related to race, gender, and handicaps.

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